BASELINE REMEDIAL STRATEGY REPORT

REMEDIAL DESIGN FOR AQUIFER RESTORATION

INFORMATION ONLY

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
FERNALD, OHIO

JUNE 1997

U.S. DEPARTMENT OF ENERGY
FERNALD AREA OFFICE

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(TASK 1)

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AWWT	advanced wastewater treatment [facility]
BSL	biodenitrification surge lagoon
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
FEMP	Fernald Environmental Management Project
FRL	final remediation level
FS	feasibility study
IAWWT	interim advanced wastewater treatment
IEMP	Integrated Environmental Monitoring Plan
MCL	maximum contaminant level
O&M	operation and maintenance
OEPA	Ohio Environmental Protection Agency
OSDF	on-site disposal facility
PRRS	Paddys Run Road Site
RI	remedial investigation
ROD	record of decision
SSOD	storm sewer outfall ditch
TI	technical impracticability
SPIT	South Plume interim treatment
SWIFT	Sandia Waste Isolation Flow and Transport [model]
SWRB	storm water retention basin

Section 1.0

1.0 INTRODUCTION

The Record of Decision (ROD) for Operable Unit 5 at the U.S. Department of Energy's (DOE's) Fernald Environmental Management Project (FEMP) was signed on January 31, 1996, setting in motion the remedial design (RD) process for the FEMP's Great Miami Aquifer groundwater restoration remedy (DOE 1996a). As the first formal deliverable required under the ROD, the U.S. Environmental Protection Agency (EPA) and Ohio Environmental Protection Agency (OEPA) approved the Operable Unit 5 RD Work Plan in July, 1996. The RD Work Plan outlines 11 design tasks and the associated design deliverables and schedule necessary to convey the design of the Great Miami Aquifer groundwater remedy for agency review and approval (DOE 1996b).

Task 1 of the approved RD Work Plan requires the DOE to prepare a Baseline Remedial Strategy Report that is intended to 1) serve as the technical basis for the detailed design of the FEMP's groundwater remedy and 2) summarize the results of the FEMP's ongoing enhancement modeling simulations that have been conducted following approval of the initial remedial strategy (termed the "base case" remedy) contained in the Operable Unit 5 Feasibility Study (FS) Report (DOE 1995a). This report fulfills the requirements for the Baseline Remedial Strategy Report as specified under Task 1 of the RD Work Plan.

1.1 ROLE OF THE FS "BASE CASE" REMEDY

The Operable Unit 5 FS Report and ROD outlined the site-wide remediation strategy for restoration of the aquifer, including the integration of existing actions into the final remedy. Under this overall strategy, restoration will be accomplished using a series of area-specific groundwater restoration modules and the centralized water treatment capabilities of the FEMP's advanced wastewater treatment (AWWT) facility. Each area-specific module will be brought on line as needed during the life of the remedy and independently withdrawn from service once remedial objectives within an area are achieved. The installation sequence and operation of the modules will follow a coordinated schedule that is based on the schedule and availability of access to the areas occupied by the source-control operable units (Operable Units 1 through 4) and the modeling projections of the duration and intensity of restoration actions necessary to achieve desired site-wide cleanup time frames and satisfy discharge requirements to the Great Miami River.

In order to demonstrate the feasibility of restoring the aquifer in a reasonable time frame, the Operable Unit 5 FS Report identified a "base-case" system consisting of 28 conventional extraction wells (packaged into four discrete modules) and system-wide pumping rates of approximately 4000 gpm, representing the hydraulic capacity of the aquifer beneath the FEMP beyond which undesirable drawdown conditions would be likely. Modeling simulations for the base case system indicated the aquifer could be restored in an estimated 27-year time frame at a total present worth cost of about $160 million (of which the majority of the costs are attributed to long-term operations and maintenance [O&M] costs accompanying groundwater treatment).

It was acknowledged in the FS Report and the ROD that the remedial design process would build upon the base case and evaluate additional scenarios that incorporated innovative enhancement technologies (such as groundwater injection) to further reduce remediation time, pumping-related hydraulic impacts, and cost. It was also acknowledged in the FS Report that the FEMP would implement EPA's "learn as you go and respond accordingly" improvement process for groundwater restoration that is contained in EPA's General Methods for Remedial Operation Performance Evaluations (EPA 1992). As envisioned by this guidance, once a base case remedy is selected for a site and documented in a ROD, ongoing efforts to improve system efficiency and respond to actual field conditions and performance results should be extended over the life of the remedy.

In the FS Report, DOE formally recognized the desire to incorporate this "learn as you go" philosophy into the modular, step-wise design and implementation strategy for the aquifer restoration program. Lastly, it was also acknowledged in the FS Report that the remedial design process would address EPA's desire to restore the off-property portion of the plume as the FEMP's highest groundwater priority.

1.2 ROLE OF THE BASELINE REMEDIAL STRATEGY REPORT

As the followup groundwater strategy document to the Operable Unit 5 FS and ROD, the role and intent of the Baseline Remedial Strategy Report is four-fold:

1) To report on the results of the enhancement modeling simulations that extend beyond the FS base-case system, including an evaluation of groundwater injection and the refinements necessary to enhance restoration of the off-property portion of the plume.

2) To recommend a final restoration strategy to serve as the design basis for the full-scale program.

3) To provide FEMP decision-makers with a perspective concerning the plausible range of estimated cleanup times and costs associated with the "in-the-field" performance of the final recommended strategy.

4) To assess the impact of recent landowner-imposed access constraints on the number and locations of off-property extraction wells and associated pipe lines contemplated for restoring the off-property portion of the plume.

Affected off-property landowner noted in Item 4 above has raised objections to two of the four off-property wells proposed in the preliminary baseline strategy identified in this report. To support discussions with the landowner and EPA and OEPA, a series of additional modeling simulations were performed to evaluate alternatives for addressing the landowner-imposed access constraints. Additional modeling simulations were also performed after the October 1, 1996 submittal of the draft report to incorporate the new Geoprobe sampling results. All the additional modeling simulations are presented in Appendix E and are summarized in Section 5.0 of the report, along with a proposed path forward for addressing the landowner concerns as well as the final extraction well locations based on the updated uranium plume. Appendix G describes the Geoprobe sampling task which was initiated in November of 1996 to verify the lateral and vertical extents of the current uranium plume south of the SSOD and in the off-property area.

The aquifer restoration program at the FEMP is a major activity that will take considerable time and resources to complete. As will be highlighted throughout this report, a number of factors cause uncertainty in the actual time and resources necessary to successfully complete the program. DOE, EPA, OEPA and other FEMP decision-makers need to fully understand the significance of the uncertainties in order to make well-informed decisions concerning how the program will be implemented both initially and at later stages of the cleanup.

The assessment of the performance of the recommended strategy contained in this report is intended to provide decision-makers with a perspective on: the hierarchy of issues and factors that drive uncertainty; the general likelihood of them happening; and the overall effect of the uncertainties on groundwater cleanup time and cost. This assessment has been provided so that decision-makers and affected stakeholders are aware of the sensitivity of the groundwater remedy to changes in the factors, and are prepared for future decisions should changes in the factors be experienced later during full-scale implementation. It is important to highlight that the recommended strategy conveyed in this report is intended to be an improvement over the FS base-case remedy. The evaluation of the uncertainties associated with the performance of this improved strategy is not intended as a retreat from any of the commitments for groundwater restoration contained in the Operable Unit 5 ROD.

One of the primary motivations for the final strategy contained in this Baseline Remedial Strategy Report is the FEMP's recent commitment to a new, accelerated cleanup plan designed to complete source-control actions and facility dismantlement and dispositioning (D&D) activities by the year 2005. This accelerated plan, designated as the FEMP's "Ten Year Plan", is focused on reducing long-term site operating and maintenance costs (and therefore total costs) by completing site restoration on a quicker, more aggressive schedule. These long-term costs are dubbed by DOE as "mortgage costs" and DOE has made a programmatic commitment to reducing such costs as the cornerstone of a recent ten-year goal to complete environmental restoration activities at DOE's facilities nationwide (Alm 1996).

At the time the Operable Unit 5 FS was prepared, completion estimates for the FEMP's source-area remediation and facility D&D activities were in the range of 25 to 30 years, based on funding profiles in existence at that time. These source-area completion estimates in turn controlled the pace of groundwater restoration because, as demonstrated in the FS, continued source loading from the source areas and physical access to the aquifer for direct groundwater extraction within the source areas were the key noted constraints that ultimately controlled the projections of cleanup time in the areas where the highest contaminant concentration levels are found.

Also at the time of the Operable Unit 5 FS, it was recognized that the FEMP's wastewater treatment infrastructure would need to be available over a 25 to 30 year period, to support the water treatment needs of the FEMP's other operable units. Incremental increases in long-term O&M costs, attributable to the treatment of groundwater over the estimated 27 year life of the FS base case remedy, were concluded to be relatively insignificant since the infrastructure supporting groundwater treatment would be in place to accommodate other needs that existed over this same duration.

Current funding profiles, however -- based on the new Ten Year Plan -- indicate that source-area remediation and facility D&D can be accomplished up to 15 or more years earlier than initial estimates. Although actual completion of the groundwater cleanup is not a formal element of the FEMP's Ten Year Plan, the strategy conveyed in this Baseline Remedial Strategy Report 1) recognizes the earlier access to the source-control areas that will be achievable with the FEMP's Ten Year Plan; and 2) intends to fulfill DOE's programmatic expectations to reduce long-term mortgage costs (consistent with the motivations of the Ten Year Plan) wherever possible by identifying cost-effective measures to achieve aquifer restoration sooner. As part of this intention, the strategy recognizes that with the Ten Year Plan in place, the FEMP's long-term O&M costs associated with water treatment extending beyond the ten year end date would be solely attributable to the groundwater treatment needs of the FS base case remedy.

In accordance with these programmatic intentions, four new potential groundwater cleanup time targets were examined as part of the Baseline Strategy Report: 25, 15, 10, and 7.5 years. These targets were developed to first explore this fundamental question: "Is it possible to shorten groundwater restoration time to be more consistent with the Ten Year Vision that has been formulated for the FEMP?" If such shortening is within the realm of possibility (defined by the available geochemical and hydraulic data for the site), the targets would also facilitate the comparison of the cost implications of shortening the remediation schedule (thereby reducing long-term O&M costs) against the increased capital costs necessary to accommodate the additional infrastructure needed for a shorter remediation time.

Using best available existing (i.e., pre-implementation) data and cost projections, the overall objective of the report is to select a preferred strategy that balances up-front capital expenditures against the desired reduction in long-term mortgage costs in a manner consistent with DOE's programmatic goals and available funding profiles. Following the selection of the preferred strategy, an uncertainties analysis was conducted to provide an understanding of how cleanup time and cost for the preferred strategy are influenced by uncertainties in all of the major factors contributing to remedial performance.

It is acknowledged that the preferred strategy conveyed in this report will recommend an initial set of remedy components (numbers of wells, locations, operating parameters, and resultant estimated area-specific cleanup times) that may need to be re-evaluated or adjusted over the course of the restoration activity as post-implementation performance data become available and actual costs are realized.

1.3 KEY FACTORS AFFECTING CLEANUP PERFORMANCE

As mentioned in the preceding section, the baseline strategy evaluation is being conducted using best available existing (pre-implementation) information regarding aquifer physical properties and the expected costs associated with the remedial elements comprising the program. However, a number of factors cause uncertainty in the time and resources that will be necessary to successfully complete the program. This section summarizes the major factors that were evaluated in the report and those which were specifically used to conduct the sensitivity analyses and quantitative uncertainty evaluations. The factors are listed under two categories: 1) those considered to be "human factors" (and which were evaluated qualitatively) and 2) those considered to be "natural factors" (which were evaluated quantitatively as part of the sensitivity analyses). Both types of factors are important and can have similar levels of impact on overall system performance (i.e., cleanup time and cost).

1.3.1 Human Factors

Human factors represent those factors affecting remedy performance that can be controlled by engineering design, funding commitments, or O&M procedures. They also include other man-made constraints associated with present or future activities conducted by other nearby parties (e.g., Southwest Ohio Water Company and the Paddys Run Road Site). The major human factors that can be influenced by DOE and which were considered for the baseline strategy report are:

- Well Design and Installation (as an example, the differences in installation risk between horizontal and vertical wells)
- Source-Area Remediation Schedule (which affects the duration of source-area loading to the aquifer and availability of access to the aquifer for direct groundwater extraction from "hot-spots" beneath source areas)
- Operation and Maintenance of the Restoration System (as an example, inefficient wells or treatment plant performance as a result of inadequate capacity maintenance could reduce the volume of water that can be extracted from the aquifer and therefore lead to longer cleanup times).
- Availability of Funding (unavailability of short-term funding can delay installation of system components, leading to longer cleanup times; unavailability of long-term funding can result in reduced level of operations and/or maintenance and corresponding longer cleanup times)

The uncertainties associated with these factors were generally evaluated qualitatively, as part of the initial selection process used to identify a preferred preliminary baseline scenario from among the four new scenarios evaluated. The effect of human factors are generally represented by simplifying assumptions (which can only be confirmed "after the fact)" rather than being subject to field testing as for the natural factors discussed below.

1.3.2 Natural Factors

Natural factors represent those factors affecting remedy performance that are intrinsic to the environmental media where the contaminants currently reside. Natural factors cannot be easily modified by engineering measures and therefore represent constraints on the engineering approach and system design. Examples include climatological change, physical properties of the aquifer, and the ongoing geochemical interactions between the contaminants and the aquifer matrix.

Three major natural factors that affect cleanup time and cost for the aquifer were considered in the Baseline Remedial Strategy Report:

- The hydraulic characteristics and capacity of the aquifer, which limit total pumping rates based on the need to achieve desired aquifer drawdown profiles within the target cleanup zone and at neighboring off-property locations. Of prime concern is the need to minimize hydraulic impacts at the Paddys Run Road Site (where a second groundwater plume associated with that site is located) immediately south of the off-property portion of the FEMP's groundwater plume.
- The geochemical processes that occur within the aquifer, which control the amount of contaminant mass removal accompanying each pore volume exchange during restoration.
- The deleterious effects of iron bacteria on the long-term performance of injection wells.

Although they cannot be easily changed, these three natural factors are amenable to field testing to provide necessary design information (rather than relying solely on assumptions, as with the human factors).

The Great Miami Aquifer has been well characterized and evaluated during the course of 10 years of Remedial Investigation (RI) studies at the FEMP. Information has been obtained in sufficient detail to develop a preferred remedy and evaluate its anticipated performance. However, a degree of uncertainty remains for precise prediction of system performance and, at some point, it is necessary to implement the remedy and react to the results obtained before further insights into the aquifer conditions that affect cleanup time can be gained. This recognition is consistent with EPA remedy performance assessment guidance (EPA 1992).

The uncertainties associated with the first two natural factors were used to conduct the uncertainties analyses regarding the range of performance (cleanup times and cost) anticipated for the preferred restoration scenario. The discussion of these uncertainties is presented in Appendix F. However, it is difficult to quantify potential deleterious effects of iron bacteria on the long-term success for the groundwater injection operation. If the expected benefits of groundwater injection do not materialize due to iron precipitation problems, the actual groundwater cleanup time may not be significantly shorter than the 27 years time frame estimated in the Operable Unit 5 FS. The full-scale Groundwater Injection Demonstration along the FEMP southern fenceline planned for 1998 will provide more information for re-evaluating long-term feasibility, operation and maintenance requirements, and effects of groundwater injection.

1.4 PROCESS FOR FUTURE REMEDIAL DECISIONS

Strategy presented in this Baseline Remedial Strategy Report provides a recommended course of action based on the best understanding of site conditions available at this time. It is important to emphasize that the recommendation does not specify an exact enforceable reduction of restoration time frame that must be achieved at all costs. Rather, it identifies a preferred shorter restoration time frame based on the anticipated behavior of the aquifer and the expected performance and cost of additional remedial components, consistent with EPA groundwater guidance. The anticipated behavior of the aquifer (and the contamination) is based primarily on groundwater modeling predictions. It needs to be recognized that a groundwater model, by design, is a simplification of the natural system and cannot fully represent all of the localized conditions occurring in the aquifer such as preferential flowpaths and pockets of low permeability zones. These conditions may lead to localized differences between model predictions and actual conditions experienced. However, the initial remedial decisions regarding system design (i.e., remedial infrastructure and operational conditions) still need to be based on the best available modeling result.

At some point in the future, as actual operating conditions are experienced and performance results are obtained, the FEMP's primary decision-makers (DOE, EPA, OEPA, and affected stakeholders) may be confronted with a need to modify the operating strategy of the groundwater remedy from that recommended initially by this report. These modifications may be the consequence of imprecise assumptions or representations regarding the previously described key human and natural factors affecting remedy performance.

As a result of the uncertainty accompanying the key factors, the following operating situations (and accompanying remedial decisions) may develop as future performance information is compiled:

- Aquifer restoration is proceeding at or ahead of the desired target, and hydraulic impacts conform to expectations (Pending decision: no need to modify remedy)

- Aquifer restoration is proceeding at or ahead of the desired target, but hydraulic impacts are greater than desired (Pending decision: need to reduce net extraction rates, with a resulting potential increase in cleanup time)

- Aquifer restoration is proceeding behind the desired target, but hydraulic impacts are less than anticipated and additional extraction capacity is therefore available (Pending decision: need to evaluate best course of action from among several alternatives: increase net extraction rates with existing wells; add additional wells; or extend cleanup times)

- Aquifer restoration is proceeding behind the desired target, but hydraulic impacts are as desired and no additional extraction capacity is available (Pending decision: may need to extend cleanup time as only viable option; if rates of progress become asymptotic, may need to pursue different enhancement technologies (possibility of using lixiviants, pulse pumping, etc.) or a technical impracticability waiver to terminate operations. The need for such enhancements would require further detailed evaluations as to their applicability and effectiveness.

These examples of conditions and situations that may be encountered in the future indicate that tradeoff evaluations could be necessary and that such tradeoffs will need to consider both the physical capabilities of the system and the most cost-effective path forward. The preferred course for some situations may result in adding additional infrastructure (resulting in increased capital cost) in order to preserve desired cleanup times and/or avoid additional long-term operational costs. In other cases, the preferred course may result in the need to extend cleanup time as the fiscally responsible decision. These decisions will need to be made on a case-by-case basis based on the physical and cost constraints imposed (recognizing DOE's programmatic objective to reduce site mortgage costs as tempered by available funding profiles), and under the collective agreement of DOE, EPA, OEPA, and affected stakeholders.

Section 2.0

2.0 OVERVIEW OF THE BASELINE REMEDIAL STRATEGY REPORT

This section provides background information on the FEMP's current remedial design and implementation efforts; summarizes the objectives of the baseline groundwater remediation strategy; and outlines the contents of the remaining four sections and accompanying six appendices of the document.

2.1 BACKGROUND

As part of the approved FS and ROD, the FEMP's groundwater remediation levels, acceptable remediation time frames, and other regulatory constraints (e.g., outfall discharge concentration limits) have all been defined. The selected base case remedy contained in the FS and ROD identified the need for 28 extraction wells (see Figure 2-1), 4000 gpm groundwater extraction rates, 2000 gpm of dedicated effective groundwater treatment capacity, and almost 30 years to restore the aquifer. In concept, the base case remedial strategy demonstrated the feasibility of restoring the aquifer and attempted to employ the minimum number of conventional extraction wells necessary to achieve capture and cleanup of the FEMP's on- and off-property groundwater plumes within a reasonable time frame. However, such an approach is not necessarily the optimal strategy in terms of treatment requirements and durations (which have a profound effect on long-term O&M costs). The estimated present worth cost of the base case FS strategy is about $160 million, of which the most significant portion is attributed to the operation of the groundwater treatment facility. The estimated duration of groundwater treatment for the base case FS remedy is more than 20 years.

In order to gain an early start on groundwater restoration, five extraction wells were installed in 1993 at the leading edge of the off-property South Plume as part of the EPA-approved South Plume Removal Action. The original intention of the South Plume Removal Action was to prevent the further southward migration of the off-property portion of the groundwater plume, while the FEMP's ongoing RI/FS and remedy selection efforts were being finalized. The South Plume Removal Action system has been operating since the fall of 1993 and has removed over 1.9 billion gallons of water and more than 265 pounds of uranium from the South Plume to date.

In 1996, nine new on-property extraction wells comprising the South Field Extraction System module were installed in the vicinity of the South Field and the storm sewer outfall ditch (SSOD) features at u:*5crw2*dgn*map*hor*dpth*stpln001.dgn

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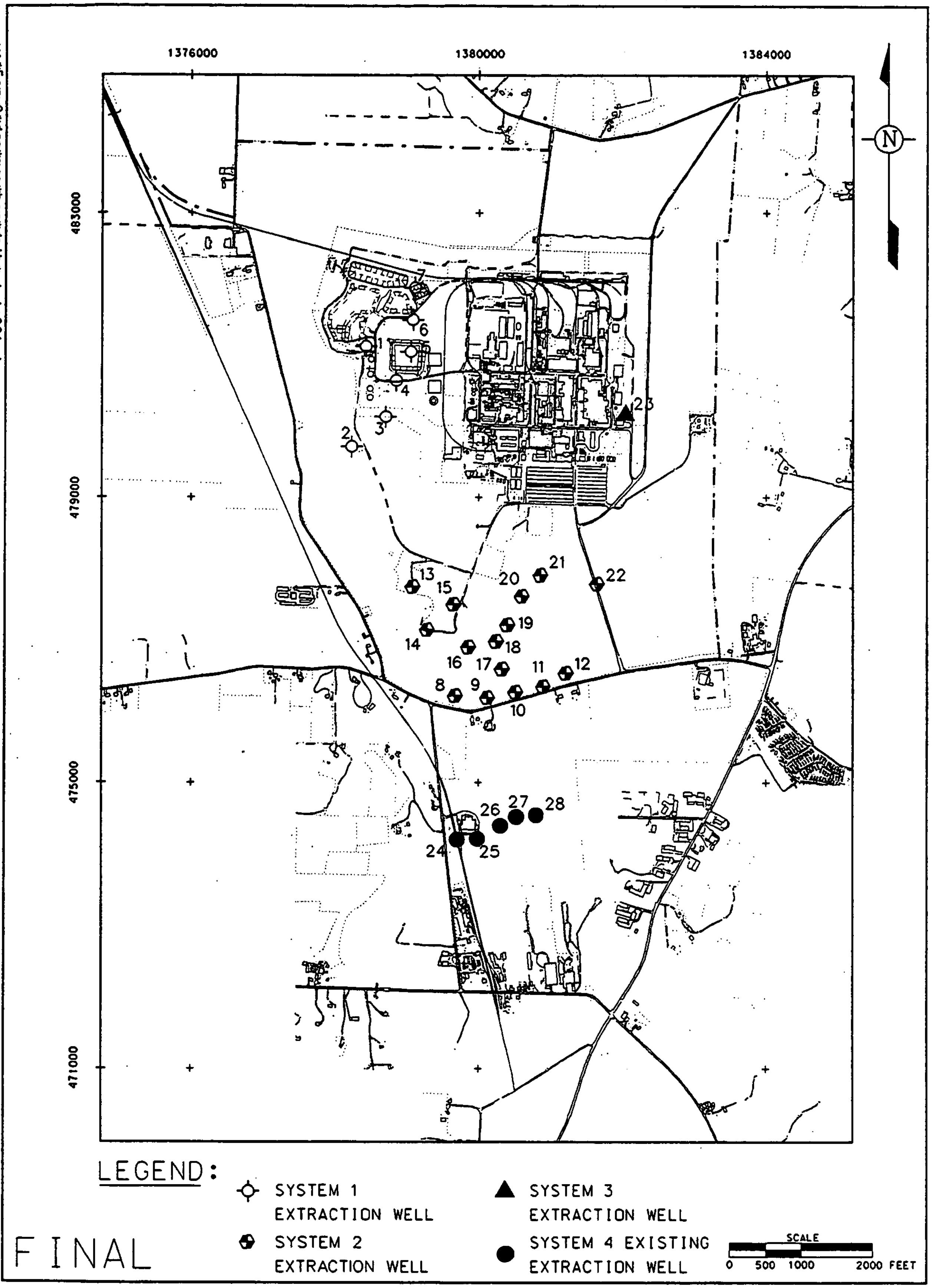

FIGURE 2-1. EXTRACTION WELL LOCATIONS - FS STRATEGY

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the site, as part of an EPA-approved early start initiative ahead of the issuance of the Operable Unit 5 ROD. The design of the piping network for the nine wells is currently being finalized and the network will be installed under the provisions of the Operable Unit 5 Remedial Action (RA) Work Plan. These nine wells are designed to aggressively remove groundwater contamination in an on-property area where uranium contamination levels in the aquifer are highest. The piping network designs for both the South Plume Removal Action and the South Field Extraction System include additional tie-in points that will facilitate future rounds of expansion as appropriate.

A number of enhancements to the Great Miami Aquifer groundwater remediation strategy proposed in the Operable Unit 5 FS have been evaluated following approval of the FS and incorporation of the base case remedy in the Operable Unit 5 ROD. These revisions were deemed necessary because of the shortened source-area remediation schedule accompanying the FEMP's Ten Year Plan, examination of additional supporting technologies (such as groundwater injection), and the DOE's ongoing commitment to further enhance the restoration of the off-property portion of the South Plume.

2.2 OBJECTIVES

One of the major objectives of this report is to summarize the predicted performance of a series of new groundwater remediation scenarios which have been developed and evaluated following completion of the Operable Unit 5 FS Report. Key technical approaches developed previously as part of the FS (such as the sequential/paused operation of the extraction system modules and the employment of maximum net extraction rates) were generally maintained in these new potential scenarios. However, the new scenarios also incorporate remedial technologies not previously evaluated in the FS such as groundwater injection and horizontal wells. The latest source-area remediation schedule (based on the FEMP's Ten Year Plan) and a more realistic approach for modeling the transition of aquifer geochemical conditions during remediation were also used to develop and evaluate the new scenarios.

In order to improve contaminant mass removal efficiency, several of the new scenarios include the placement of additional vertical extraction wells in groundwater "hot spots" beneath the FEMP's primary source areas, once source-area remediation activities are complete. One of the scenarios evaluates the use of horizontal wells to reach source-area hot spots prior to the completion of source-area remediation. This scenario also evaluates horizontal wells as an alternate means to remediate the off-property portion of the South Plume. In general, the new scenarios employ additional measures to shorten restoration (and groundwater treatment) time frames and reduce the overall hydraulic impacts to the aquifer during the restoration activity.

The other primary objective of the Baseline Remedial Strategy Report is to document the selection of the preferred groundwater remediation scenario from among the new alternatives. Four cleanup time targets were included in the new scenarios: 25, 15, 10, and 7.5 years. These targets were used to compare the cost implications of shortening the remediation schedule (thereby reducing long-term O&M costs) against the increased capital costs necessary to accommodate the additional infrastructure needed for a shorter remediation time. The scenario-specific performance measures, relative costs, inherent risks/uncertainties, and operation and maintenance issues were all considered during the selection process. A leading strategy was selected based on the preliminary evaluations and carried forward for detailed evaluation and modification. During the detailed evaluation, necessary modifications to the selected strategy to accommodate off-property landowner constraints and the FEMP's current long-term funding profile were evaluated and incorporated into the selected strategy as appropriate.

Following selection of the recommended scenario, a sensitivity/uncertainty analysis was performed to bracket the range of estimated cleanup times and costs associated with the recommended scenario. Three additional simulations were conducted to provide an understanding of how cleanup time and cost are influenced by uncertainties in the major factors considered. The results of the evaluations are provided in Appendix F and summarized in Section 5.3.

Finally, operational considerations and guidelines regarding groundwater treatment decisions (and compliance with the ROD's Great Miami River discharge limits) were developed through the remedy performance evaluations. These guidelines will serve as the foundation for the operating procedures to be developed in the Operations and Maintenance Plan, which will be produced under Task 2 of the RD Work Plan.

2.3 REPORT ORGANIZATION

Figure 2-2 presents an overview of the Baseline Remedial Strategy Report and the process used to arrive at a final strategy. Sections 1.0 and 2.0 of the report present introductory information and provide an overview of the Baseline Remedial Strategy Report. Section 3.0 summarizes the commitments, constraints, and goals to be incorporated in the new groundwater remediation scenarios along with the general assumptions used in their formulation. Section 4.0 presents the scenarios and provides an assessment of their predicted performance based on best estimates and assumptions for the major factors affecting remedy performance. The assessments provided in Section 4.0 also assume full funding and unimpeded off-property access for the implementation of the scenarios. A leading baseline strategy is selected from among the preliminary alternatives at the conclusion of Section 4.0. Section 5.0 finalizes the baseline remedial strategy through the evaluation of funding-based implementation constraints and off-property landowner access concerns. The remedy performance projections associated with the final baseline remedial strategy are also presented in Section 5.0, along with the results of a sensitivity analysis of the factors and uncertainties affecting cleanup time and cost. Section 6.0 then summarizes the conclusions and key operational considerations regarding the final baseline remedial strategy.

Six appendices are included at the end of the report to present additional details of the modeling approach (Appendix A), horizontal well applications (Appendix B), cost estimates (Appendix C), groundwater treatment systems (Appendix D), simulations conducted to address off-property landowner access concerns and finalize the baseline strategy (Appendix E), sensitivity analyses of the factors and uncertainties that affect cleanup time and cost for the recommended strategy (Appendix F), and additional field sampling results and interpretations of the current uranium plume (Appendix G).

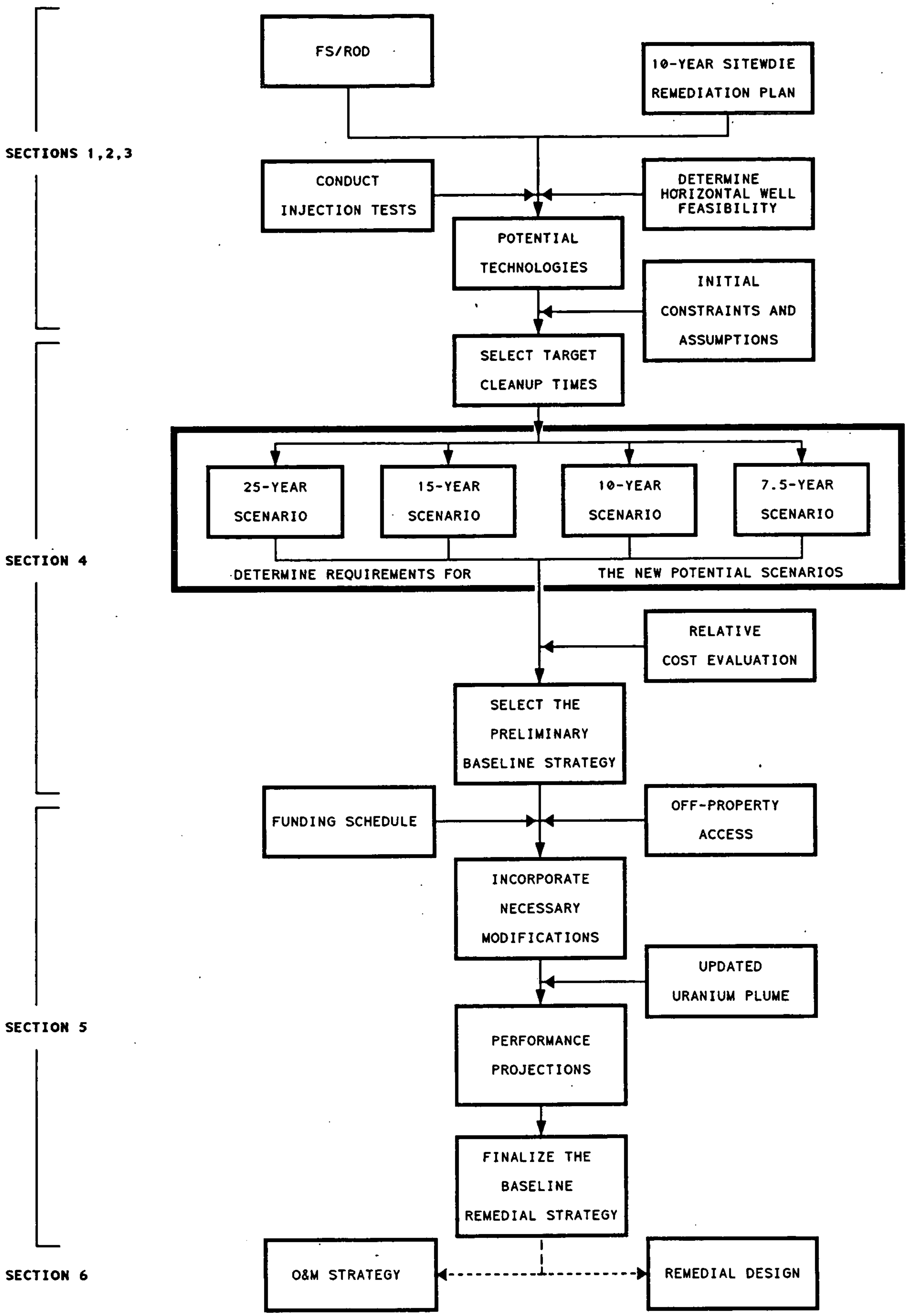

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FIGURE 2-2 FINALIZATION OF THE GROUNDWATER BASELINE REMEDIAL STRATEGY

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Section 3.0

3.0 COMMITMENTS, CONSTRAINTS, AND ASSUMPTIONS

An acceptable groundwater remediation strategy for the FEMP needs to satisfy the commitments and constraints that have previously been defined through regulatory agency interactions and review of earlier FEMP RI/FS documents. The existing commitments and constraints to be considered when developing the scenarios are summarized in this section. General assumptions regarding factors that can affect the feasibility and effectiveness of the potential remedial scenarios are also presented. Because uranium is the predominant groundwater contaminant at the FEMP, it has been used to define the major constraints as well as to evaluate the effectiveness of the groundwater remediation strategy. Therefore, most of the commitments, constraints, and assumptions are related to the distribution and behavior of uranium in the aquifer.

3.1 COMMITMENTS

The key aquifer restoration commitments which are formally recognized for development of the scenarios are discussed below. These specific commitments have their origin in the Operable Unit 5 ROD or in subsequent discussions with EPA and OEPA regarding the performance of the existing South Plume Removal Action system.

3.1.1 Aquifer Cleanup Levels

The FEMP's final remediation levels (FRLs) for groundwater were presented in the Operable Unit 5 FS Report and ROD. In general, the FRLs were based on maximum contaminant levels (MCLs) (or 10^{-5} incremental lifetime cancer risk or 0.2 hazard index when no MCL is available). For uranium, the predominant contaminant at the FEMP, the proposed MCL of 20 parts-per-billion (ppb) was selected as the FRL. As required by the Operable Unit 5 ROD, groundwater remediation is to take place until all constituent-specific groundwater concentrations in the aquifer are below the established FRLs or until a technical impracticability (TI) waiver can be justified.

Areas of the Great Miami Aquifer exceeding FRLs will be restored primarily through groundwater extraction methods. The areas of the aquifer requiring remediation are identified in Figure 3-1. As noted on Figure 3-1, the administrative boundary for aquifer restoration to be addressed is north of the Paddys Run Road Site plume. DOE's role and involvement in OEPA's ongoing assessment and/or cleanup of the Paddys Run Road Site plume, if any, would be defined separately as part of the

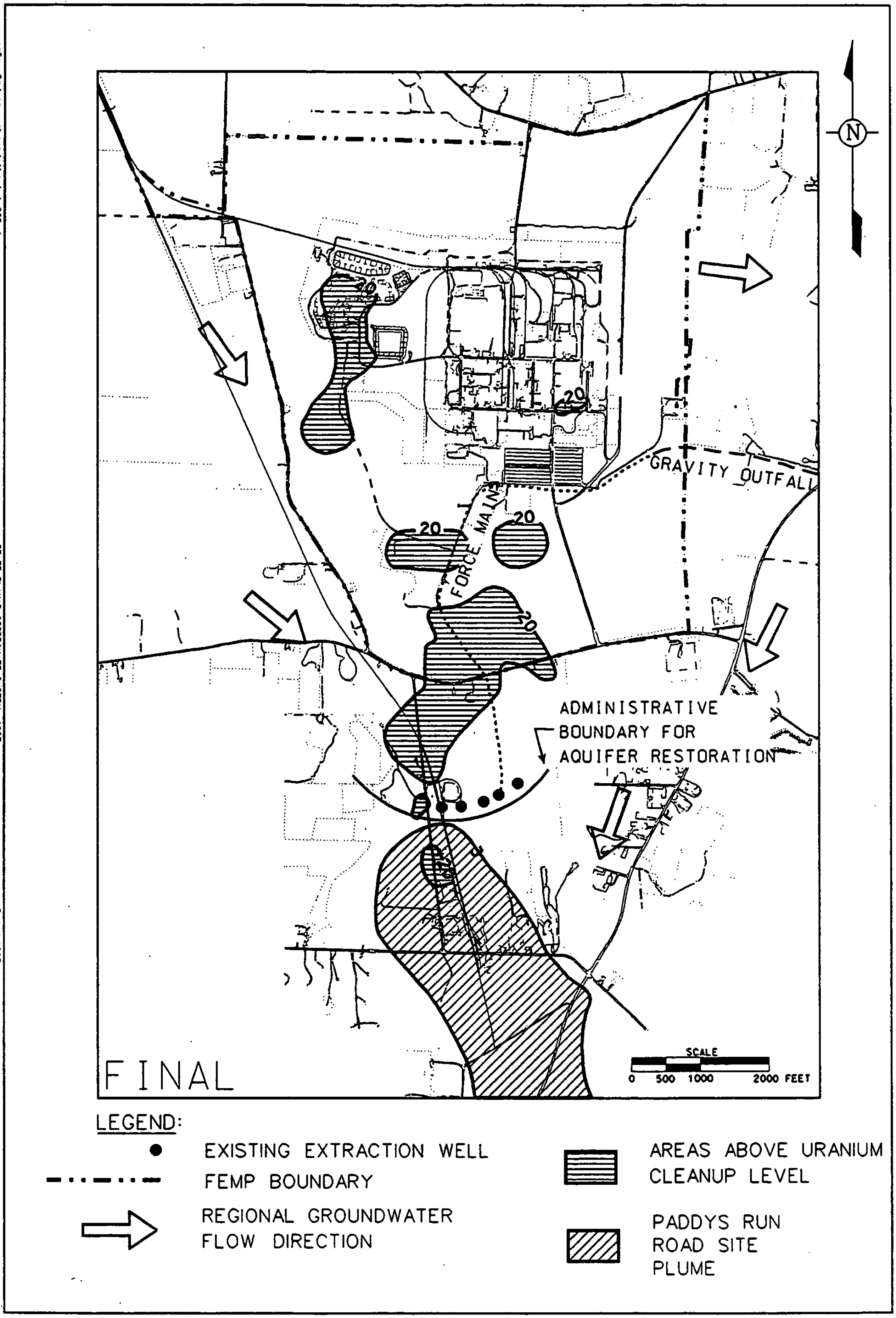

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FIGURE 3-1. AREAS OF THE GREAT MIAMI AQUIFER REQUIRING REMEDIATION

Paddys Run Road Site response obligations and in accordance with the Paddys Run Road Site project schedule. Monitoring will continue south of the administrative boundary as identified in the Integrated Environmental Monitoring Plan (IEMP) (DOE 1996c), until such time as the need for action is established and implemented.

It is important to be clear that the FEMP's groundwater cleanup levels are concentration-based, rather than mass-based. Although mass-removal metrics provide a useful index for comparing alternative remedial strategies, the goal is to restore the aquifer to the concentration-based FRLs as the final measure of success. Those strategies that can achieve the FRLs uniformly (i.e. achieve uniform concentration levels throughout the plume footprint at completion) will generally be the most resource efficient, although they may not necessarily remove the most mass from the aquifer.

3.1.2 Discharge Outfall Limits

During site remediation, significant amounts of both treated and untreated water will be discharged to the Great Miami River. Treatment will be applied to storm water, wastewater and recovered groundwater to the extent necessary to limit the total mass of uranium discharged through the FEMP outfall to the Great Miami River to 600 pounds per year. This mass-based discharge limit became effective upon issuance of the ROD. Additionally, the necessary treatment will be applied to these streams to limit the concentration of total uranium in the blended effluent to the Great Miami River to 20 ppb. The 20 ppb discharge limit for uranium will be based on a monthly average and will become effective January 1, 1998. Beginning in 1998, up to 10 events per year are allowed for emergency by-pass due to storm events (i.e., such events will be accounted for in the annual mass-based discharge requirement but not in the monthly average concentration calculations).

Ongoing compliance with other NPDES requirements during the remediation is also a commitment recognized by the FEMP.

3.1.3 Treatment Capacity

A dedicated groundwater treatment capacity of at least 2000 gpm (including existing and new treatment capacities) will be made available for groundwater restoration. It is expected that this dedicated capacity can be achieved by adding new equipment within the confines of the existing AWWT facility. Additional treatment capacity beyond the 2000 gpm dedicated capacity may also be available during dry seasons or when the other remediation-related wastewater flows decrease. When the treatment system is stabilized and additional AWWT improvements are incorporated, the anticipated uranium concentration in groundwater treatment effluent is expected to be around 5 ppb.

3.1.4 Groundwater Treatment Decision

Wherever possible, the piping networks that convey extracted groundwater will be designed to connect all the new extraction wells via double headers, with one connected to the main line to the treatment plant and the other to the main discharge line. The extracted groundwater can then be sent to either the treatment plant or directly to the discharge outfall. Through this arrangement, the treatment or discharge decision for each new well can be made on a well-by-well basis. The existing South Plume Removal Action wells will be handled as a unit, with the treatment decision made based on the combined concentration occurring in the existing South Plume force main. During remediation, only extracted groundwater with uranium concentrations higher than 20 ppb at individual wellheads will be treated, up to the available treatment capacity. When the extracted groundwater with concentrations higher than 20 ppb exceeds the treatment capacity, groundwater from wells which have relatively higher uranium concentrations will be treated preferentially. The remaining extracted groundwater will bypass treatment and be directly discharged under the regulatory constraints noted above.

3.1.5 Aquifer Cleanup Time

The 27-year projected aquifer restoration time frame associated with the base case FS remedy was deemed as a reasonable time frame for cleanup in the Operable Unit 5 ROD. However, shorter restoration time frames are preferred by EPA and OEPA, and the FS contained a commitment on the part of DOE to further evaluate measures to reduce cleanup time as a part of remedial design. Shortening the cleanup time can reduce the length of treatment plant operations which may result in significant total cost savings, although a higher up-front capital cost may be required. The scenarios developed for this report have been formulated to specifically address DOE's commitment to evaluate measures to shorten remediation time frames for both the on- and off-property areas of the FEMP.

3.1.6 South Plume Optimization Commitments

The term "South Plume Optimization" was coined during EPA's review of the April 1995 South Plume Removal Action report and signifies the desire of EPA, OEPA, and DOE to restore the off-property portion of the plume quickly and cost effectively. Because the original design of the existing South Plume Removal Action was for plume containment purposes rather than active restoration, a review of measures to enhance the performance of the South Plume recovery well system has been specifically requested by EPA and OEPA. Additional off-property extraction wells in the South Plume and groundwater injection wells along the FEMP's southern property line are being evaluated in the baseline scenarios to increase mass removal efficiency and reduce the off-property cleanup time.

In the intervening period while such measures are under evaluation, containment of the South Plume will continue and potential hydraulic impacts to the adjacent Paddys Run Road Site will be kept to a minimum during operations.

3.2 PERFORMANCE GOALS

In addition to the regulatory-based commitments recognized above, the preliminary aquifer remediation scenarios will also strive to achieve the following specific performance goals:

Minimize Hydraulic Impacts

- Initiate groundwater remediation modules in sequence
- Minimize the net extraction rate
- Minimize the cumulative groundwater table drawdown
- Minimize the on- and off-property cleanup time
- Containment of the 20 μg/L total uranium plume.

Maximize the Mass Removal Efficiency

- Complete installation of additional extraction wells as soon as possible based on unconstrained funding and landowner access
- Install extraction wells directly in groundwater hot spots
- Extract directly from contaminated aquifer layer
- Focus the available pumping capacity in extraction wells with higher groundwater concentrations
- Adjust operational conditions with the progression of remediation

Minimize Impacts to Wastewater Treatment Operations

- Develop representative estimates of the extracted groundwater quality

- Develop representative estimates of groundwater treatment needs
- Minimize the potential for suspended solids in the extracted groundwater

Maximize the Usefulness of Monitoring Data

- Utilize current monitoring data to update the groundwater model
- Evaluate the monitoring data frequently to determine system effectiveness and potential problems
- Utilize modeling results to help specify future monitoring
- Update the monitoring program frequently with the progression of remediation

Minimize the System Downtime

- Incorporate preventive considerations into the system design
- Incorporate lessons learned through the operation of the South Plume Extraction System (i.e., design and placement of well screens, management of iron fouling concerns, electrical surge protection, and pump design)
- Operate within the design envelope
- Establish effective preventive maintenance procedures
- Prepare for potential corrective maintenance needs (spare equipment)

Minimize the Overall Remediation Cost

- Shorten the cleanup time where cost effective
- Minimize required treatment capacity

3.3 OTHER CONSTRAINTS

There are additional constraints imposed on the groundwater remediation strategy due to factors such as aquifer characteristics, injection water sources, soil remediation schedules, and funding availability. These constraints also affect the implementability of any potential remedial strategy.

3.3.1 Extraction Rate

The net groundwater extraction rate should not exceed the recharge rate of the regional aquifer or cause excessive water table drawdown. Following technical evaluation, 4000 gpm was established as the limit for the net extraction rate for the aquifer in the Operable Unit 5 FS Report. The maximum pumping rate for each individual well should not exceed 500 gpm (again based on technical evaluations conducted for the FS) in order to prevent excessive local drawdown and improve uranium mass removal efficiencies. Hydraulic impacts to the groundwater contamination plume at the Paddys Run Road Site south of the existing South Plume recovery wells should also be kept to a minimum.

3.3.2 Injection Rate and Quality

Injection may be applied to reduce groundwater drawdown and to increase the groundwater flushing rate through the plume. Based on results of a field injectivity test, an injection rate as high as 450 gpm per well is achievable in the Great Miami Aquifer (DOE 1995d). However, due to areas of high iron concentrations in the Great Miami Aquifer and the existence of iron bacteria, the issue of geochemical compatibility between water types when injecting water into the aquifer needs to be considered in order to maintain long-term efficiency of groundwater injection in any well. The first short-term injection test conducted in October 1995, used untreated (not treated for iron) groundwater from the South Plume area and rapidly resulted in a significant well-plugging problem (DOE 1995d). Results of the second short-term injection test, conducted in March 1996, indicate that when treated (for iron) groundwater was used, plugging did not occur after 5 days of continuous injection at 200 gpm.

No water with a total uranium concentration greater than 20 ppb should be used for injection. Extracted groundwater (treated and untreated) is considered the only significant source of water available for injection. However, mixing the extracted groundwater from multiple wells in order to achieve a blended concentration less than 20 ppb for injection is not considered acceptable to the regulatory agencies. From a regulatory standpoint, extracted groundwater with uranium concentration below 20 ppb (before mixing with extracted groundwater from other wells) could be acceptable for injection without treatment. However, as indicated by the geochemical problems encountered during the field injection tests, using untreated groundwater for injection may not be feasible (DOE 1995e) due to high potential of iron precipitation which may quickly clog up the injection well screen. Therefore, the only acceptable source of injection water is the treated water produced by the AWWT facility. The treatment process will also reduce iron content in the extracted groundwater.

3.3.3 Surface Access

Most of the groundwater plumes are located underneath contaminated soil and source-area waste materials. However, large-scale soil and source-material remediation will first be conducted north of the SSOD (i.e., in the Operable Unit 1, 2, and 3 areas). Due to these surface remediation activities, certain areas will not be directly accessible for installation and operation of groundwater wells until completion of these activities. A 20-year duration was assumed for soil remediation in the Operable Unit 5 FS Report. A shorter soil remediation schedule under the Ten Year Plan will allow an earlier start of groundwater extraction operations directly in the groundwater hot spots. It is assumed for the scenarios evaluated in this report that well installations within the Operable Unit 1, 2, and 3 areas can be initiated within seven years.

Access issues are also important with the off-property plume. Affected landowners must be willing to accommodate an array of remedial elements (wells, pipelines, electrical tie ins, monitoring and maintenance activities, safety and security measures, replacement/relocation actions, etc.) on their properties as part of the restoration program. The modeling simulations conducted for the initial selection of the preliminary baseline strategy (Section 4.0) do yet not consider any access constraints or logistical issues that may ultimately be important to off-property landowners. The modifications to the selected baseline strategy (presented in Section 5.0) do consider such issues or constraints, where known.

3.3.4 Available Funding

With more vertical and/or horizontal extraction wells, certain groundwater remediation scenarios may be able to achieve shorter cleanup times and therefore lower total remediation cost. But it is also recognized that, due to uncertainty about available funds, remediation scenarios that will require higher up-front capital costs may not be implementable.

Ideally, a remedial strategy should be developed according to the most likely funding scenario, but estimation of a realistic funding scenario is difficult. Therefore, although the estimated up-front capital costs for certain remediation scenarios may be very high, the preliminary evaluation of potential strategies needs to be performed assuming sufficient funds will be available for each of the potential remediation scenarios (i.e., under an unconstrained funding situation). From the potential strategies, a preliminary remedial strategy would then be selected according to relative cost-effectiveness under the unconstrained case. Necessary modifications to the preliminary strategy would then be made based on the actual funding schedule (i.e., under a constrained funding case) when it becomes known. This was the process used to develop the final remedial strategy (presented in Section 5.0) from the preliminary remedial strategy selected in Section 4.0.

3.4 GENERAL ASSUMPTIONS

General assumptions incorporated in the groundwater transport modeling that have significant impacts on the predicted performance of the remediation scenarios are briefly summarized in this section.

3.4.1 Target Plumes

As in the Operable Unit 5 FS Report, the target plumes used in the model are conservatively based on the maximum uranium concentrations measured in each groundwater monitoring well. Although the current/actual uranium plume might be smaller, this approach ensures that all the evaluated remediation scenarios will be able to maintain full capture and to achieve the cleanup goals in time, with a potential trade-off of lower estimated mass removal efficiencies (i.e., the mass of uranium removed per unit volume of groundwater extracted) because of well placement. Uranium concentration contours of the targeted "maximum condition" plume are shown in Figure 3-2. After the preliminary evaluation, the estimated cleanup time and groundwater treatment needed for the selected remedial strategy can be refined using the latest "current-condition" groundwater plume data.

3.4.2 Surface Remediation Schedule

The source operable unit remediation schedules accompanying the FEMP's new Ten Year Plan will be used to develop all of the new groundwater restoration scenarios. This assumption allows earlier initiation of vertical well installations and operations in areas where soil remediation will take place first. Contaminant source loadings due to vertical infiltration through the source areas as well as contaminated surface runoff during remediation will be terminated earlier. It is assumed that all of the area north of the SSOD will be accessible in about 7 years and all soil remediation will be completed in 10 years. The direct contaminant source loadings from Operable Units 1 and 2 will be terminated at the end of the 7th year (i.e., 2002) and surface runoff contaminant concentrations will be reduced to postremediation conditions at the end of the 10th year.

3.4.3 Treatment Capacity Schedule

The groundwater treatment capacities for the first and second years (i.e., 1996 and 1997) are assumed to be 400 and 850 gpm, respectively. The expanded total effective groundwater treatment capacity of

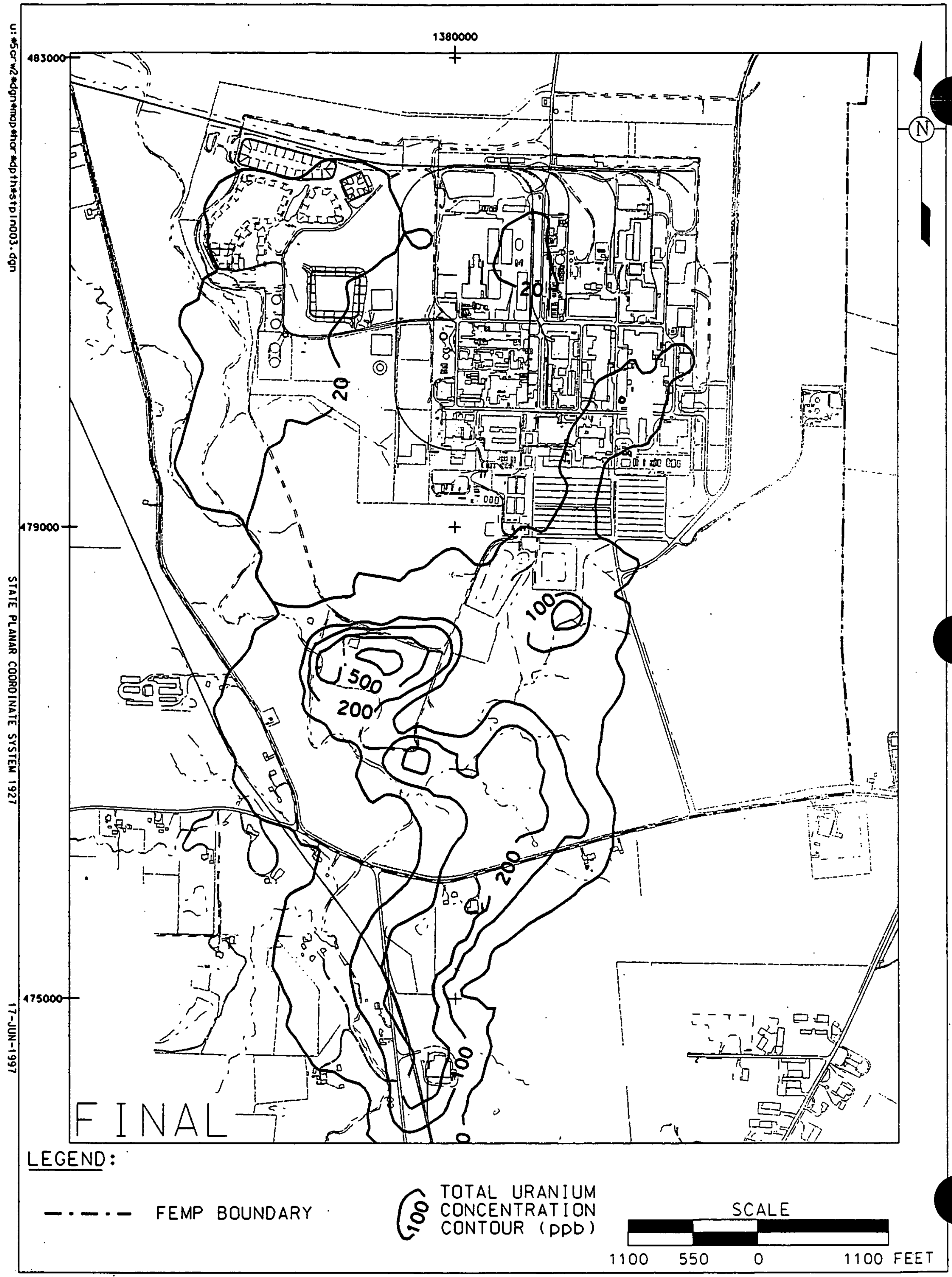

FIGURE 3-2. TARGETED URANIUM PLUME FOR PRELIMINARY EVALUATION

2000 gpm will be available starting from the third year (1998). If the initially predicted uranium concentrations exceed 20 ppb at the outfall line in a potential remediation scenario, the additional treatment capacity required to satisfy the concentration limit will also be estimated for scenario-specific cost estimation purposes. For any scenario in which additional treatment capacities are required, the cost of the additional capacity will be added to the scenario-specific overall cost by adding increments of 250 gpm treatment modules. The inclusion of the incremental treatment capacities for such scenarios are included for scenario comparison purposes only.

3.4.4 Geochemical Conditions

One key variable that will need to be assessed closely during the course of the remedial program is the mass of uranium and other contaminants of interest that are held in the aquifer solids and unavailable for desorption (i.e., the chemisorbed and precipitated uranium). As discussed in Appendix A, there is no standard way to represent this condition in simulation modeling using the conventional distribution coefficient, K_d. (K_d represents a simple adsorption model where a linear adsorption isotherm holds). Several studies indicate that simple linear isotherm models do not fit observations of contaminant behavior in aquifers, as adsorption becomes less reversible as time increases (Lasaga 1981; Di Toro and Horzempa 1982, 1983; Voice and Weber 1983). When the contaminant mass available for desorption decreases with time, less contaminant is partitioned into fresh groundwater drawn over the aquifer matrix during the restoration process (see discussion provided in Appendix A). The lower contaminant concentration in groundwater may be interpreted as an increase in the K_d value and a decrease in the efficiency of the restoration process, when it is really a decrease in the mass of the contaminant available for desorption. This is not seen as a detrimental process, because it is assumed that groundwater concentrations will stabilize at a concentration below the contaminant's designated clean-up level. However, assumptions are needed on the use of K_d to account for this behavior in the fate and transport model.

In general, the time dependent change in the mass of contaminant available for desorption is a primary factor in the decreasing contaminant recovery rates and long cleanup times that are often experienced with pump and treat groundwater systems. To model the time dependent change in the release of contaminants from the aquifer matrix several assumptions must be made to handle the mass of contaminant retained by the aquifer matrix and, most difficult, the time continuum over which the contaminant becomes fixed to the aquifer matrix.

Variation in the mass of the contaminant retained by the aquifer matrix can be approached by noting the difference in measured adsorption ratios versus desorption ratios (see Appendix A where these terms are defined). Over time, the desorption ratios increase relative to the adsorption ratio as contaminant is tied up in the aquifer matrix by chemisorption or precipitation. Therefore, the assumption is made that the K_d is represented by the adsorption and desorption ratios, and uncertainty in the cleanup cost and time associated with different adsorption and desorption ratios is evaluated by using these ratios to bracket the range in K_d values.

The range in adsorption and desorption ratios measured for uranium in the Great Miami Aquifer indicates that the ratios are different, with the desorption ratio generally higher in value. It is also important to emphasize that differences in adsorption and desorption ratios have been noted in short-term batch tests, although these tests are not considered definitive examples of the long-term geochemical processes that will occur over the full time of aquifer restoration. However, directly measured adsorption and desorption ratios are used to set a potential range of K_d values that are used to evaluate uncertainty in projected cleanup time and costs. Appendix A provides additional information on assumptions behind the use of K_d in the evaluation of remedial strategies. Ultimately, the long-term impact of the selected K_d value on aquifer restoration needs to be assessed (and responded to) based on actual operating experience and sampling and analysis.

To account for the decrease in uranium available for desorption, and to bound estimates of cleanup time and treatment capacities, a range in the K_d values will be used to implement simulations of the remediation scenarios. The K_d values are assumed to reflect representative adsorption and desorption ratios of 1.78 and 17.8 L/kg, respectively. Additional assumptions (e.g., timing of the K_d transition) behind the use of K_d in these simulations can be found in Appendix A.

One expected impact of using the desorption ratio (17.8 L/kg) to represent K_d is lower mobility of uranium in the aquifer (i.e., about 10 times slower under the same hydraulic gradient). Therefore, to minimize the distance of uranium transport, additional extraction wells may be placed in areas of former sources to recover uranium released from potentially abundant chemisorption and precipitation sites in these local areas. In areas where initial uranium contamination is not significant (i.e., less than 200 ppb), the presence of chemisorbed and precipitated uranium may result in shorter cleanup times, because less uranium will be released from an aquifer matrix containing these residual forms and the concentration-based uranium cleanup level can be met earlier.

Because the Sandia Waste Isolation Flow and Transport (SWIFT) model can only simulate one K_d value in each simulation, multiple model runs and superimposition of results are required to combine different timings of transitions among the recovery well systems. A more detailed description of this modeling procedure is provided in Appendix A.

As mentioned in Section 3.3.2, iron clogging of the injection wells and/or the aquifer matrix in close proximity to the wells, due to geochemical interactions between the aquifer and the injected water, is a potential site-specific obstacle that has been evaluated with several short-term single-well injectivity tests. It is assumed for the development of the baseline strategy that the potential iron clogging problem can be resolved and groundwater injection can be conducted with reliable long-term efficiency at the FEMP. However, it needs to be recognized that contingency actions may need to be developed and activated in the future (such as using reduced rates of groundwater injection) should the geochemical interactions become a detrimental factor and unresolvable through further engineering measures. The aquifer restoration O&M Plan (to be developed under Task 2 of the RD Work Plan) will address monitoring, maintenance, and operating procedures needed to track and address this potential factor.

Section 4.0

4.0 PRELIMINARY EVALUATION OF POTENTIAL STRATEGIES

4.1 TECHNICAL APPROACH AND ASSUMPTIONS

The preliminary evaluations were conducted to develop potential cost effective approaches for shortening the remediation time for the Great Miami Aquifer restoration program, to evaluate the effectiveness of groundwater enhancement technologies, and to acknowledge the benefits of the shorter remediation schedules for the FEMP's source control operable units under the accelerated (ten year) remedial plan.

4.1.1 Technical Approach

Four time-based remedial scenarios representing a range of aquifer cleanup times (7.5, 10, 15, and 25 years) were evaluated by conducting model simulations to determine the required number of extraction and injection wells and required groundwater treatment capacity necessary to satisfy the regulatory and technical commitments and constraints discussed in Section 3.0. The capital and O&M costs required for each strategy were estimated based on the Operable Unit 5 FS cost estimate tabulations and actual well installation and AWWT operational costs experienced to date with the FEMP's South Plume Removal Action. A cost-effectiveness comparison among the potential strategies was then performed to identify the most promising cost-effective strategy, in recognition of DOE's programmatic goals to reduce long-term site mortgage costs wherever possible. Following selection, the preferred scenario is then described and compared to the original base case FS remedy. The description includes an identification of the necessary groundwater extraction and injection modules and the implementation schedule which will be required to complete the aquifer restoration in the designated time frame.

The SWIFT GMA Model is used for simulating the three dimensional contaminant transport in the Great Miami Aquifer in this study. The SWIFT code is a fully coupled, transient, 3-dimensional finite difference model for groundwater flow through both porous and fractured media. The mass transport equations solved include terms for convection, dispersion, retardation by sorption, and decay or degradation of the contaminant. The SWIFT code, originally developed by Sandia National Laboratory in the late 1970s for the High Level Waste Program, has been revised several times to increase its capability and to change computer platforms. The site-specific SWIFT GMA model was originally calibrated in 1989 (DOE 1993a). The model was redesigned and recalibrated based on additional data including the South Plume pump test results (DOE 1993b and DOE 1994). The model has been applied intensively to support all the RI/FS activities at the FEMP since the completion of model development. Based on results of the more recent hydraulic tests and operational data from the South Plume recovery well system in the past three years, the model generally can closely match the measured field hydraulic conditions (DOE 1995c, DOE 1995d, DOE 1996d). The specific procedures applied in the SWIFT model simulations conducted for this report are described in Appendix A.

4.1.2 Assumptions

In order to simplify the development of the potential remedial scenarios, the following assumptions were made for the preliminary evaluation:

- Target Plumes - The "maximum" uranium plume as shown in Figure 3-2 was used as the initial plume in the groundwater and contaminant fate and transport model, consistent with the simulation runs conducted for the Operable Unit 5 FS. The administrative boundary for aquifer restoration is shown in Figure 3-1. As noted on Figure 3-1, this boundary is north of the Paddys Run Road Site plume.

- Surface Remediation Schedule - All the area north of the SSOD will be accessible in about 7 years and all soil remediation will be completed in 10 years. The direct contaminant source loadings from Operable Units 1 and 2 will be terminated at the end of the 7th year (i.e., 2002) and surface runoff contaminant concentrations will be reduced to postremediation conditions at the end of the 10th year.

- Treatment Capacity Schedule - The groundwater treatment capacities for the first and second years (i.e., 1996 and 1997) are assumed to be 400 and 850 gpm, respectively. The baseline total effective groundwater treatment capacity of 2000 gpm will be available starting from the third year (1998). For those scenarios requiring additional groundwater treatment beyond the planned AWWT expansion, the additional capacity is assumed to be added by using increments of 250 gpm treatment modules. Treatment decisions will be made on a well-by-well basis except for the existing South Plume Recovery Well System, which will be made on a combined flow basis.

- Source of Injection Water - Treated groundwater and extracted groundwater with wellhead concentrations less than 20 ppb (without treatment) can be injected. It is assumed that the iron precipitation problem will not significantly reduce the efficiency of the injection wells.

- Geochemical Conditions - An area-specific one-time transition in the uranium K_d from 1.78 L/kg to 17.8 L/kg was assumed to take place after source termination and the first few pore volumes of contaminated groundwater have been extracted from the area. This transition was implemented to reflect the continuing increase in K_d that occurs over time as chemisorption processes become predominant in later stages of remediation. It was further assumed that groundwater injection can be conducted with reliable long-term efficiency using treated groundwater and that no geochemical interferences would arise.

- Off-Property Access - Areal access for additional off-property wells for South Plume optimization purposes was assumed available without any landowner imposed constraints.

- Funding - For the preliminary evaluations, sufficient funds were assumed to be available to implement each of the potential remediation scenarios, and funding constraints are therefore not present.

4.2 DESCRIPTION OF THE POTENTIAL GROUNDWATER REMEDIATION SCENARIOS

Four additional potential groundwater remediation scenarios were developed for the preliminary evaluations based on the Operable Unit 5 FS base case strategy as well as the commitments, constraints, and assumptions previously discussed. Each scenario represents a remediation system that can achieve groundwater cleanup within a shorter time frame than was specified in the FS base case strategy. In order to cover a sufficiently wide range of capital and long-term O&M costs for analysis, the cleanup time frames targeted in the preliminary evaluations are for 25, 15, 10 and 7.5 years. During initial development, numerous adjustments to the numbers and locations of the extraction/injection wells and subsequent modeling runs were required to derive the final number of wells and locations. At the end all four remediation scenarios as presented in this section achieve the intended cleanup times and are in compliance with all the regulatory requirements and commitments.

The locations and depths of groundwater injection wells and off-property optimization wells included in these scenarios are generally based on results of previously conducted modeling studies furnished to EPA and OEPA. Results of the injection modeling study (along with a preferred approach) were presented to the EPA and OEPA in two technical information exchange meetings held in May and June of 1995. In general, the modeled groundwater injection water surface profiles (referred to as "mounds") match very well with the subsequent field injection test results conducted at the FEMP (DOE 1995d).

A synopsis of the FS strategy is first presented as the basis of all the new potential scenarios in the following subsections. Summaries of the developed specifications, predicted performances, and important design issues related to each of the four new potential remediation scenarios evaluated in this study are then provided. The groundwater model developed and applied for the RI/FS process was used to create these scenarios. A modified modeling approach, described in Appendix A, was followed to simulate the transition of uranium K_d values. Only the final modeling results for each scenario are presented.

4.2.1 Synopsis of The FS Strategy

Modeling conducted to support the Operable Unit 5 FS identified the need for at least 28 extraction wells distributed across the affected areas of the aquifer. These 28 wells are divided into four extraction well systems and are identified in Figure 2-1. The modeling conducted also demonstrated that a combined maximum pumping rate of 4000 gpm from the extraction well system will be required for up to 27 years to attain the final remediation levels. A portion of the extracted groundwater will be treated before being discharged to the Great Miami River to satisfy the outfall criteria. A dedicated groundwater treatment capacity of 2000 gpm will be required.

During the development of the FS strategy, it was assumed that site-wide soil and source-area remediation will take 20 years. Groundwater extraction by conventional vertical wells was the lead technology evaluated during the FS. It was further assumed in the FS that the vertical wells would not be installed through the contaminated source areas but rather along the downgradient edge of the groundwater contaminant plumes originating from the source areas. No additional off-property wells other than the existing South Plume Recovery Well System were employed in the FS scenario.

Assuming the uranium K_d value remains the same (i.e., 1.78 L/kg) throughout the duration of the FS strategy, it will take about 25 years and 27 years to reach a uranium remedial level of 20 ppb for the off-property and on-property areas, respectively. It is expected that with the K_d transition (employed in this Baseline study) the cleanup time for the FS strategy will exceed 30 years even under the shorter soil remediation schedule. The K_d transition will reduce both the dissolved uranium concentrations and mobility of uranium in the aquifer. Because most of the groundwater extraction wells in the FS strategy are located along the downgradient edges of the source areas, it will take a much longer travel time for the residual uranium plume to reach the extraction wells with the reduced mobility after the K_d transition. Therefore, when developing the potential scenarios in this Baseline study, additional extraction wells inside the source areas and groundwater injection are considered to offset the reduced residual uranium mobility and to facilitate faster aquifer cleanup time.

4.2.2 A Potential 25-Year Scenario

Two modifications (i.e., groundwater injection and South Plume optimization) to the Operable Unit 5 FS strategy are incorporated into this scenario. Groundwater injection operations using the five fence line wells (8, 9, 10, 11 and 12) in the original plan and five new wells (42, 43, 44, 49 and 51) north of the inactive flyash pile are included to reduce groundwater drawdown, prevent potential impacts to the Paddys Run Road Site plume, and increase groundwater flushing rates through the FEMP's contaminated zones. Four additional off-property extraction wells close to the center of South Plume (Wells 1, 2N, 3N and KN) are included to improve off-property mass removal rates from the South Plume. Among the four scenarios evaluated, this scenario makes the fewest changes to the base case FS strategy; these changes are:

- Move Well 2 from the waste pit area to the Plant 6 area
- Turn off Wells 26, 27 and 28 in the South Plume area after year 2.

4.2.2.1 Wellfield Pattern

The wellfield pattern of the 25-year scenario is shown in Figure 4-1; however, Well 22 was never used. All the extraction and injection wells are located outside of the areas where extensive soil excavations will take place. The only exception is the former production area where two extraction wells are required near Plant 6. Locations of the four new off-property extraction wells were selected considering the location of the groundwater plume as well as potential access and operational problems. In general, these off-property wells were assumed to be situated along the edge of fields and immediately away from residential dwellings.

4.2.2.2 Extraction/Injection Pumping Rate Schedule

The extraction/injection schedule used to achieve the 25-year cleanup time frame is presented in Table 4-1. The maximum extraction and injection pumping rates are 500 and 200 gpm, respectively. Because no wells will be installed inside the inactive flyash pile even after soil remediation, an earlier start of upgradient groundwater injection is necessary to increase flushing rates through the contaminated zone and ensure a reasonable cleanup time. Groundwater injection wells located along the fence line are used as a hydraulic barrier to prevent the plume from moving off property and to

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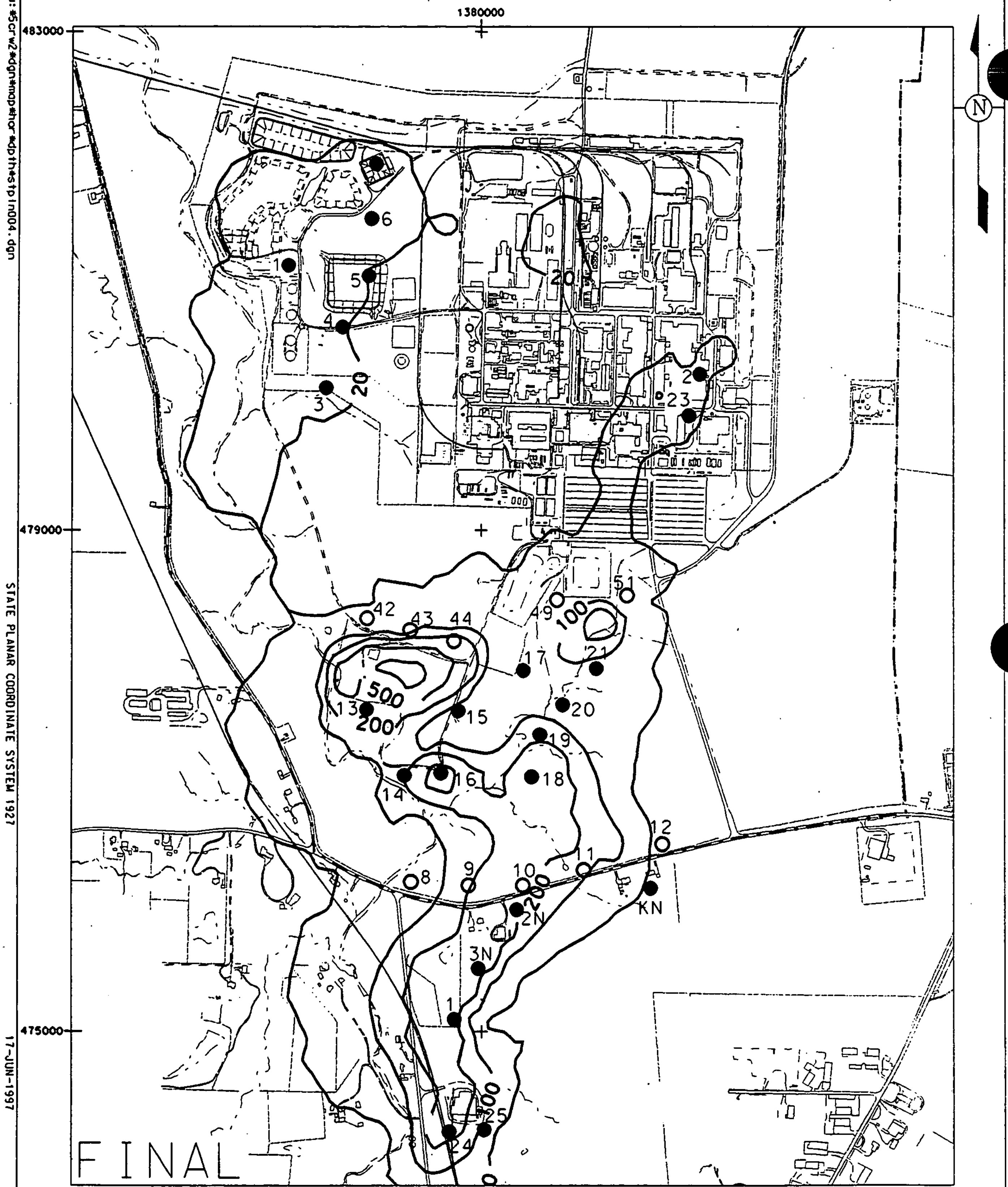

LEGEND:

- FEMP BOUNDARY
- EXTRACTION WELL
- INJECTION WELL

100 TOTAL URANIUM CONCENTRATION CONTOUR (ppb)

SCALE

1100 550 0 1100 FEET

FIGURE 4-1. WELL LOCATIONS FOR 25-YEAR SCENARIO

000042

TABLE 4-1

EXTRACTION/INJECTION SCHEDULE USED FOR 25-YEAR SCENARIO

		Pumping Rates (gpm) (+) = Pumped (-) = Injected				
Location	Well No.	Years 0 to 2	Years 3 to 7	Years 8 to 10	Years 11 to 20	Years 21 to 25
Waste pits	1	0	0	100	0	0
Waste pits	3	0	0	100	120	0
Waste pits	4	0	0	100	120	0
Waste pits	5	0	0	100	120	0
Waste pits	6	0	0	100	120	0
Waste pits	7	0	0	100	120	0
Totals		0	0	600	600	0
Plant 6	2	0	0	250	0	0
Plant 6	23	0	0	250	0	0
Totals		0	0	500	0	0
Fenceline injection wells	8	0	-200	-200	0	0
Fenceline injection wells	9	0	-200	-200	0	0
Fenceline injection wells	10	0	-200	-200	0	0
Fenceline injection wells	11	0	-200	-200	0	0
Fenceline injection wells	12	0	-200	-200	0	0
Totals		0	-1000	-1000	0	0
South Field	13	0	300	300	300	0
South Field	14	0	300	300	400	500
South Field	15	0	300	300	400	500
South Field	16	0	300	300	500	0
South Field	17	0	100	200	0	0
South Field	18	0	100	200	0	0
South Field	19	0	100	200	0	0
South Field	20	0	100	200	0	0
South Field	21	0	100	200	0	0
Totals		0	1700	2200	1600	1000
South Field injection wells	42	0	-200	-200	-200	-200
South Field injection wells	43	0	-200	-200	-200	-200
South Field injection wells	44	0	-200	-200	-200	0
South Field injection wells	49	0	-200	-200	0	0
South Field injection wells	51	0	-200	-200	0	0
Totals		0	-1000	-1000	-600	-400
South Plume	24	300	300	300	0	0
South Plume	25	300	300	300	0	0
South Plume	26	400	0	0	0	0
South Plume	27	400	0	0	0	0
South Plume optimization	1	0	250	250	0	0
South Plume optimization	2N	0	150	150	0	0
South Plume optimization	3N	0	350	350	0	0
South Plume optimization	KN	0	150	150	0	0
Totals		1400	1500	1500	0	0
Total pumping		1400	3200	4800	2200	1000
Total injecting		0	-2000	-2000	-600	-400
Net aquifer extraction		1400	1200	2800	1600	600

eliminate the effects of a groundwater stagnation zone in the South Plume area (which slows off-property cleanup time) that was identified in the FS strategy. Injection along the fence line is considered critical for achieving an earlier cleanup of the off-property groundwater south of the FEMP. Therefore, operation of the two groundwater injection systems starts at the earliest time possible, year 3 (1998).

4.2.2.3 Predicted Performance

System performance measures including years of groundwater treatment, extracted groundwater concentrations to and by-passing the treatment plant, blended outfall concentrations, and uranium mass removed are listed in Table 4-2. Because of the high injection rate used in the early stage, additional groundwater treatment capacity (beyond that planned for the AWWT facility expansion) is required under this scenario to maintain acceptable outfall concentrations. Groundwater treatment is required for 20 years. Due to the high initial concentrations in the South Field area and the transition of the uranium K_d value used in the simulations, the overall cleanup time of this scenario (i.e., 25 years) is not significantly shorter than the 27 years estimated in the FS strategy. However, cleanup time for the off-property area is significantly shorter in this scenario and water table drawdown is reduced compared to the base case FS remedy.

4.2.2.4 Summary of Significant Design Issues

In order to implement the 25-year scenario, the following design issues need to be addressed:

- Piping network for the two groundwater injection systems
- Maintaining long-term efficiency of the groundwater injection wells
- Access for the four new off-property vertical extraction wells
- Need for additional treatment capacity beyond the planned AWWT expansion.

4.2.3 A Potential 15-Year Scenario

In addition to the injection and South Plume optimization wells included in the 25-year scenario, four more vertical extraction wells at the inactive flyash pile (Wells 38, 41, 53 and 54) and four more vertical extraction wells in the waste pit area (Wells 55, 56, 57 and 58) are needed to reduce the cleanup time to 15 years. Well installation should immediately follow surface remediation in these areas. Three initial extraction wells around the inactive flyash pile (13, 14 and 16) are converted to injection wells after the new extraction wells are installed. Operation of these additional extraction/injection wells starts at the beginning of the 8th year (2002).

TABLE 4-2

SYSTEM PERFORMANCE MEASURES FOR 25-YEAR SCENARIO

Year	Total Water Pumped (gpm)	Treatment Capacity (gpm)	Water to Treatment (gpm)	Concentration to Treatment (ppb)	Water Not Treated (gpm)	Concentration Not Treated (ppb)	Uranium Extracted from Aquifer (lbs)	Injected Water (gpm)	Concentration of Injected Water (ppb)	Uranium Injected[a] (lbs)	Water Discharged (gpm)	Concentration of Discharge (ppb)	Uranium Discharged (lbs)	Uranium Removed from Aquifer (lbs)	Outfall Concentration with Additional Treatment Capacity[b]
1	1400	400	400	35.0	1000	35.0	214.5	0	N/A	0.0	1400	26.4	162.0	214.5	
2	1400	850	850	32.2	550	32.2	197.5	0	N/A	0.0	1400	15.7	96.2	197.5	
3	3200	2000	1950	127.3	1250	31.2	1256.8	2000	5.7	49.5	1200	31.2	163.9	1207.3	12.3
4	3200	2000	1950	117.7	1250	28.2	1159.1	2000	5.6	48.8	1200	28.2	148.3	1110.2	12.0
5	3200	2000	1950	104.5	1250	25.8	1033.1	2000	5.5	48.3	1200	25.8	135.4	984.8	11.8
6	3200	2000	1950	92.0	1250	23.7	915.1	2000	5.5	47.9	1200	23.7	124.6	867.3	11.6
7	3200	2000	1800	85.8	1400	21.8	809.4	2000	6.7	58.5	1200	21.8	114.5	750.9	12.4
8	4800	2000	450	39.3	4350	6.4	200.1	2000	6.1	53.5	2800	6.4	78.9	146.5	
9	4800	2000	550	44.1	4250	6.4	224.2	2000	6.0	52.3	2800	6.4	77.8	171.9	
10	4800	2000	550	49.1	4250	6.5	238.5	2000	6.1	53.1	2800	6.5	79.2	185.4	
11	2200	2000	480	42.4	1720	9.1	157.3	600	5.8	15.3	1600	9.1	63.6	142.0	
12	2200	2000	480	49.0	1720	9.1	171.5	600	5.8	15.3	1600	9.1	63.9	156.2	
13	2200	2000	480	53.1	1720	9.1	179.7	600	5.8	15.3	1600	9.1	63.4	164.4	
14	2200	2000	480	56.0	1720	8.9	184.9	600	5.8	15.2	1600	8.9	62.7	169.7	
15	2200	2000	480	58.1	1720	8.8	188.7	600	5.8	15.2	1600	8.8	62.0	173.5	
16	2200	2000	480	59.6	1720	8.7	190.5	600	5.7	15.1	1600	8.7	60.8	175.5	
17	2200	2000	480	60.7	1720	8.5	191.6	600	5.7	15.0	1600	8.5	59.7	176.6	
18	2200	2000	480	61.3	1720	8.3	191.4	600	5.7	14.9	1600	8.3	58.3	176.5	
19	2200	2000	480	61.6	1720	8.2	191.2	600	5.6	14.8	1600	8.2	57.4	176.4	
20	2200	2000	480	61.7	1720	8.0	190.0	600	5.6	14.7	1600	8.0	56.3	175.3	
21	1000	2000	0	0.0	1000	4.4	19.0	400	4.4	7.6	600	4.4	11.4	11.4	
22	1000	2000	0	0.0	1000	4.5	19.7	400	4.5	7.9	600	4.5	11.8	11.8	
23	1000	2000	0	0.0	1000	4.6	20.1	400	4.6	8.1	600	4.6	12.1	12.1	
24	1000	2000	0	0.0	1000	4.6	20.1	400	4.6	8.1	600	4.6	12.1	12.1	
25	1000	2000	0	0.0	1000	4.7	20.4	400	4.7	8.1	600	4.7	12.2	12.2	

Uranium Extracted from Great Miami Aquifer (lbs) 8184.6 Uranium Injected (lbs) 602.3 Uranium Removed from Great Miami Aquifer (lbs) 7582.3

[a]Calculated from residual uranium concentrations in injected water
[b]Assuming additional treatment capacity of 550 gpm to treat South Plume water

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4.2.3.1 Wellfield Pattern

The wellfield pattern of the 15-year scenario is shown in Figure 4-2. Even with upgradient groundwater injection, extraction wells located at the center of the plume under the inactive flyash pile will still be much more efficient than wells located at the downgradient edge (i.e., those used in the 25-year scenario and the FS strategy). Therefore, after excavation and surface regrading in the South Field and waste pit areas, additional vertical extraction wells are installed to enhance remediation. Locations of these additional extraction wells can be seen in Figure 4-2.

4.2.3.2 Extraction/Injection Pumping Rate Schedule

The extraction/injection schedule used to achieve the 15-year cleanup is presented in Table 4-3. Because additional extraction wells will be installed in remaining groundwater hot spots, injection upgradient of the inactive flyash pile can start later. The additional extraction wells and the upgradient injection wells are assumed to start operating during the 8th year. The maximum extraction and injection rates are 400 and 300 gpm, respectively. After 10 years, all the extraction and injection wells other than those in the South Field can be removed.

4.2.3.3 Predicted Performance

System performance measures including years of groundwater treatment, extracted groundwater concentrations to and by-passing the treatment plant, blended outfall concentrations, and uranium mass removed are listed in Table 4-4. Groundwater treatment is required for 10 years and no additional treatment capacity above 2000 gpm is necessary. Because the 15-year scenario achieves groundwater cleanup in a much shorter time frame than the 25-year scenario, it actually removes less total uranium mass from the aquifer; however, the mass removal efficiency is higher and less uranium will be discharged to the Great Miami River.

4.2.3.4 Summary of Significant Design Issues

In order to implement the 15-year scenario, the following design issues need to be addressed:

- Increased complexities of the extraction piping networks due to a larger number of wells
- Piping network for the two groundwater injection systems
- Converting extraction wells to injection wells
- Maintaining long-term efficiency of the injection wells
- Access for the four new off-property vertical extraction wells
- Effects from potential delays in the soil remediation schedule.

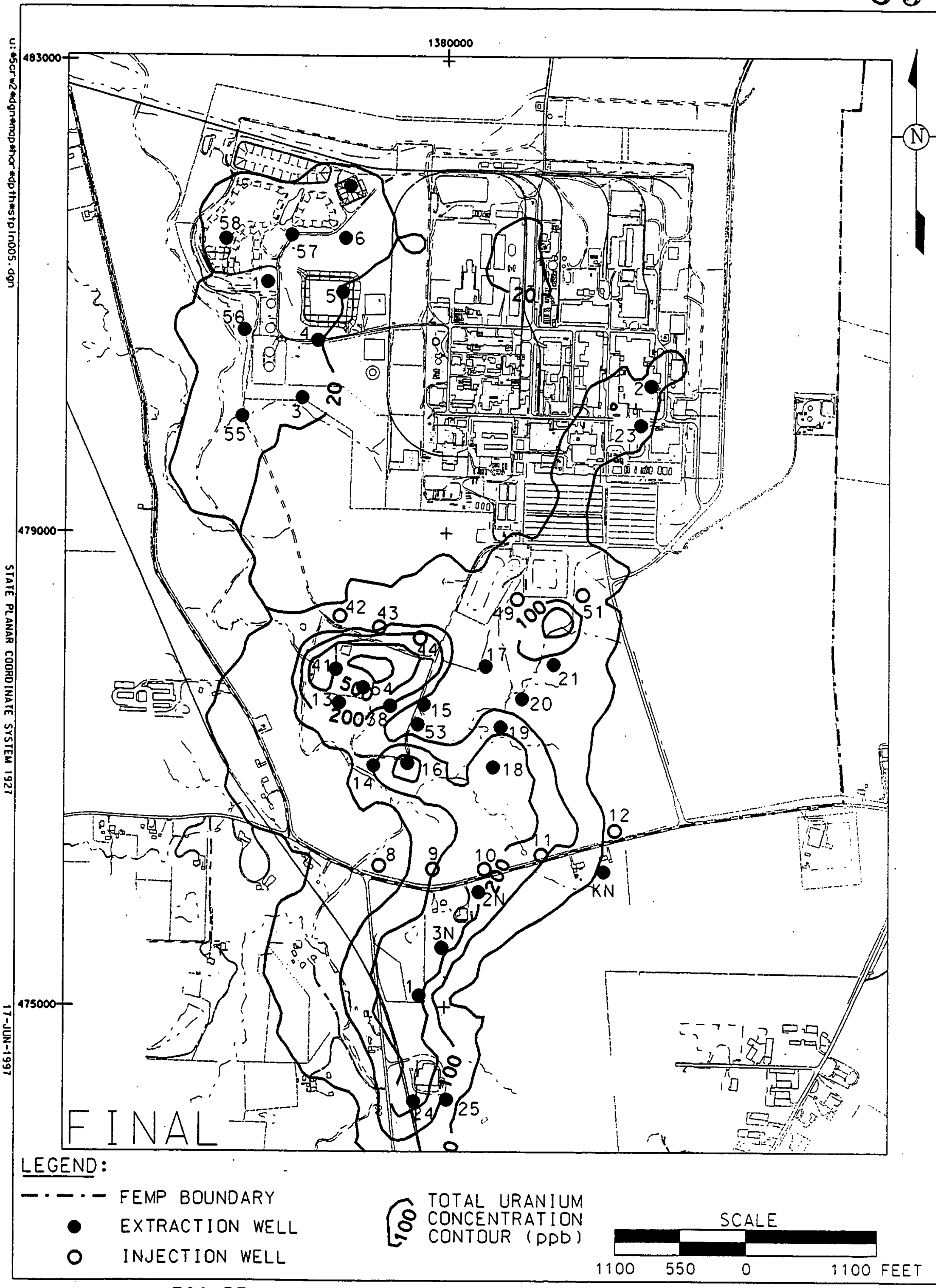

FIGURE 4-2. WELL LOCATIONS FOR 15-YEAR SCENARIO

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TABLE 4-3
EXTRACTION/INJECTION SCHEDULE USED FOR 15-YEAR SCENARIO

		Pumping Rates (gpm) (+) = Pumped (-) = Injected			
Location	Well No.	Years 0 to 2	Years 3 to 7	Years 8 to 10	Years 11 to 15
Waste Pits	1	0	0	100	0
Waste Pits	3	0	0	100	0
Waste Pits	4	0	0	100	0
Waste Pits	5	0	0	100	0
Waste Pits	6	0	0	100	0
Waste Pits	7	0	0	100	0
Waste Pits	55	0	0	100	0
Waste Pits	56	0	0	100	0
Waste Pits	57	0	0	100	0
Waste Pits	58	0	0	100	0
Totals		0	0	1000	0
Plant 6	2	0	0	250	0
Plant 6	23	0	0	250	0
Totals		0	0	500	0
Fenceline injection wells	8	0	-200	-200	0
Fenceline injection wells	9	0	-200	-200	0
Fenceline injection wells	10	0	-200	-200	0
Fenceline injection wells	11	0	-200	-200	0
Fenceline injection wells	12	0	-200	-200	0
Totals		0	-1000	-1000	0
South Field	13	0	200	-200	-300
South Field	14	0	200	-200	-300
South Field	15	0	200	200	0
South Field	16	0	200	-200	0
South Field	17	0	100	200	0
South Field	18	0	100	0	0
South Field	19	0	100	200	0
South Field	20	0	100	200	0
South Field	21	0	100	200	0
South Field	38	0	0	300	400
South Field	41	0	0	400	400
South Field	53	0	0	300	400
South Field	54	0	0	400	400
Totals		0	1300	1800	1000
South Field injection wells	42	0	0	-200	-300
South Field injection wells	43	0	0	-200	-300
South Field injection wells	44	0	0	-200	0
South Field injection wells	49	0	0	-200	0
South Field injection wells	51	0	0	-200	0
Totals		0	0	-1000	-600
South Plume	24	300	300	300	0
South Plume	25	300	300	300	0
South Plume	26	400	0	0	0
South Plume	27	400	0	0	0
South Plume optimization	1	0	250	250	0
South Plume optimization	2N	0	150	150	0
South Plume optimization	3N	0	350	350	0
South Plume optimization	KN	0	150	150	0
Totals		1400	1500	1500	0
Total pumped		1400	2800	5400	1600
Total injected		0	-1000	-2600	-1200
Net Aquifer extraction		1400	1800	2800	400

TABLE 4-4

SYSTEM PERFORMANCE MEASURES FOR 15-YEAR SCENARIO

Year	Total Water Pumped (gpm)	Treatment Capacity (gpm)	Water to Treatment (gpm)	Concentration to Treatment (ppb)	Water Not Treated (gpm)	Concentration Not Treated (ppb)	Uranium Extracted from Aquifer (lbs)	Injected Water (gpm)	Concentration of Injected Water (ppb)	Uranium Injected[a] (lbs)	Water Discharged (gpm)	Concentration of Discharge (ppb)	Uranium Discharged (lbs)	Uranium Removed from Aquifer (lbs)
1	1400	400	400	35.0	1000	35.0	214.5	0	0.0	0.0	1400	26.4	162.0	214.5
2	1400	850	850	32.2	550	32.2	197.5	0	0.0	0.0	1400	15.7	96.2	197.5
3	2800	2000	1650	95.7	1150	29.2	838.0	1000	5.0	21.9	1800	20.5	161.4	816.1
4	2800	2000	1650	88.3	1150	25.6	766.6	1000	5.0	21.9	1800	18.2	143.1	744.7
5	2800	2000	1650	80.8	1150	22.8	698.4	1000	5.0	21.9	1800	16.4	128.9	676.5
6	2800	2000	1650	74.3	1150	20.4	639.5	1000	5.0	21.9	1800	14.9	117.1	617.6
7	2800	2000	1650	68.7	1150	18.4	588.7	1000	5.0	21.9	1800	13.6	106.8	566.8
8	5400	2000	450	41.6	4950	8.9	274.3	2600	8.2	93.4	2800	8.9	108.7	180.9
9	5400	2000	450	49.4	4950	8.4	280.0	2600	7.8	89.2	2800	8.4	103.4	190.8
10	5400	2000	550	47.9	4850	7.8	280.8	2600	7.2	82.0	2800	7.8	95.6	198.8
11	1600	2000	0	0.0	1600	12.1	84.6	1200	12.1	63.4	400	12.1	21.1	21.1
12	1600	2000	0	0.0	1600	11.2	78.6	1200	11.2	58.9	400	11.2	19.6	19.6
13	1600	2000	0	0.0	1600	10.5	73.2	1200	10.5	54.9	400	10.5	18.3	18.3
14	1600	2000	0	0.0	1600	9.8	68.3	1200	9.8	51.2	400	9.8	17.1	17.1
15	1600	2000	0	0.0	1600	9.2	64.2	1200	9.2	48.2	400	9.2	16.1	16.1

Uranium extracted from Great Miami Aquifer (lbs) 5147.2

Uranium Injected (lbs) 650.6

Uranium Removed from Great Miami Aquifer (lbs) 4496.6

[a]Calculated from residual uranium concentrations in injected water.

4.2.4 A Potential 10-Year Scenario

Building on the previous scenario, it was determined that five more vertical extraction wells (59, 60, 61, 62 and 63, for a total of nine) are required in the South Field after surface remediation to further reduce groundwater cleanup time from 15 to 10 years.

4.2.4.1 Wellfield Pattern

The wellfield pattern of the 10-year scenario is shown in Figure 4-3. As described in the 15-year scenario, all the extraction and reinjection wells other than those in the South Field area can be terminated after 10 years. Therefore, additional extraction wells were only added in the South Field area to achieve cleanup within 10 years. Through iterative model simulations, it was determined that nine vertical extraction wells need to be installed after the surface remediation to achieve groundwater cleanup in the South Field area within 10 years.

4.2.4.2 Extraction/Injection Pumping Rate Schedule

The extraction/injection schedule used to achieve the 10-year cleanup is presented in Table 4-5. As in the 15-year scenario, groundwater injection upgradient of the inactive flyash pile can start later. The maximum extraction and injection pumping rates are 300 and 200 gpm, respectively. These rates are lower than those used in scenarios with fewer extraction wells.

4.2.4.3 Predicted Performance

System performance measures including years of groundwater treatment, extracted groundwater concentrations to and by-passing the treatment plant, blended outfall concentrations, and uranium mass removed are listed in Table 4-6. Groundwater treatment is required for 9 years and no additional treatment capacity above 2000 gpm is necessary. Among the three scenarios described so far, the 10-year scenario has the highest mass removal efficiency and needs to remove the least amount of total uranium mass to achieve groundwater cleanup. Uranium mass discharged into the Great Miami River is about the same as in the 15-year scenario.

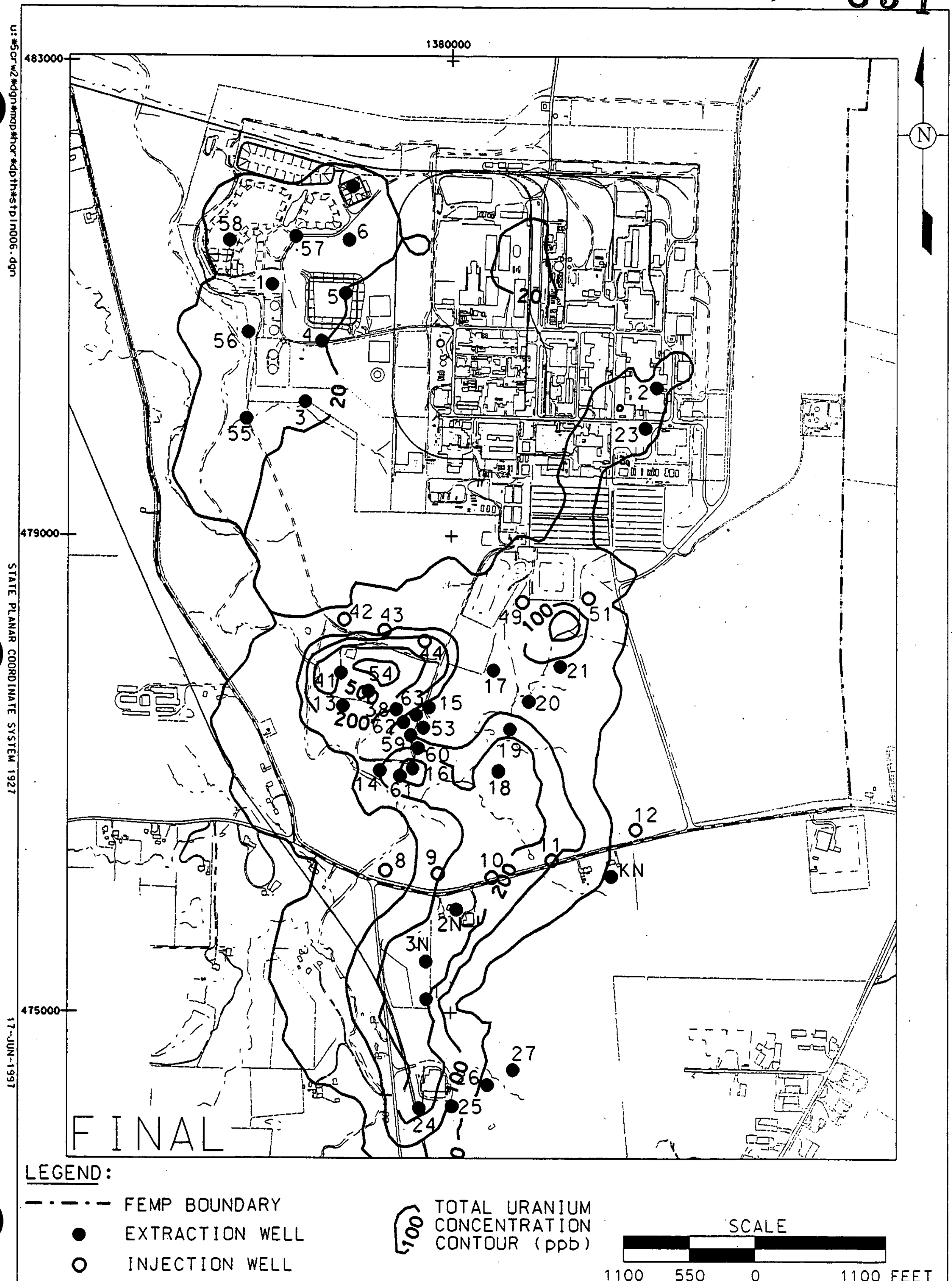


FIGURE 4-3. WELL LOCATIONS FOR 10-YEAR SCENARIO

TABLE 4-5
EXTRACTION/INJECTION SCHEDULE USED FOR 10-YEAR SCENARIO

		Pumping Rates (gpm) (+) = Pumped (-) = Injected		
Location	Well No.	Years 0 to 2	Years 3 to 7	Years 8 to 10
Waste Pits	1	0	0	100
Waste Pits	3	0	0	100
Waste Pits	4	0	0	100
Waste Pits	5	0	0	100
Waste Pits	6	0	0	100
Waste Pits	7	0	0	100
Waste Pits	55	0	0	100
Waste Pits	56	0	0	100
Waste Pits	57	0	0	100
Waste Pits	58	0	0	100
Totals		0	0	1000
Plant 6	2	0	0	250
Plant 6	23	0	0	250
Totals		0	0	500
Fenceline injection wells	8	0	-200	-200
Fenceline injection wells	9	0	-200	-200
Fenceline injection wells	10	0	-200	-200
Fenceline injection wells	11	0	-200	-200
Fenceline injection wells	12	0	-200	-200
Totals		0	-1000	-1000
South Field	13	0	200	-200
South Field	14	0	200	-200
South Field	15	0	200	100
South Field	16	0	200	-200
South Field	17	0	100	100
South Field	18	0	100	0
South Field	19	0	100	200
South Field	20	0	100	200
South Field	21	0	100	200
South Field	38	0	0	300
South Field	41	0	0	300
South Field	53	0	0	300
South Field	54	0	0	300
South Field	59	0	0	300
South Field	60	0	0	300
South Field	61	0	0	200
South Field	62	0	0	200
South Field	63	0	0	300
Totals		0	1300	2700
South Field injection wells	42	0	0	-200
South Field injection wells	43	0	0	-200
South Field injection wells	44	0	0	-200
South Field injection wells	49	0	0	-200
South Field injection wells	51	0	0	-200
Totals		0	0	-1000
South Plume	24	300	300	300
South Plume	25	300	300	300
South Plume	26	400	0	0
South Plume	27	400	0	0
South Plume optimization	1	0	250	250
South Plume optimization	2N	0	150	150
South Plume optimization	3N	0	350	350
South Plume optimization	KN	0	150	150
Totals		1400	1500	1500
Total pumped		1400	2800	6300
Total injected		0	-1000	-2600
Net Aquifer extraction		1400	1800	3700

TABLE 4-6

SYSTEM PERFORMANCE MEASURES FOR 10-YEAR SCENARIO

Year	Total Water Pumped (gpm)	Treatment Capacity (gpm)	Water to Treatment (gpm)	Concentration to Treatment (ppb)	Water Not Treated (gpm)	Concentration Not Treated (ppb)	Uranium Extracted from Aquifer (lbs)	Injected Water (gpm)	Concentration of Injected Water (ppb)	Uranium Injected[a] (lbs)	Water Discharged (gpm)	Concentration of Discharge (ppb)	Uranium Discharged (lbs)	Uranium Removed from Aquifer (lbs)
1	1400	400	400	35.0	1000	35.0	214.5	0	N/A	0.0	1400	26.4	162.0	214.5
2	1400	850	850	32.2	550	32.2	197.5	0	N/A	0.0	1400	15.7	96.2	197.5
3	2800	2000	1650	95.7	1150	29.2	838.0	1000	5.0	21.9	1800	20.5	161.4	816.1
4	2800	2000	1650	88.3	1150	25.6	766.6	1000	5.0	21.9	1800	18.2	143.1	744.7
5	2800	2000	1650	80.8	1150	22.8	698.4	1000	5.0	21.9	1800	16.4	128.9	676.5
6	2800	2000	1650	74.3	1150	20.4	639.5	1000	5.0	21.9	1800	14.9	117.1	617.6
7	2800	2000	1650	68.7	1150	18.4	588.7	1000	5.0	21.9	1800	13.6	106.8	566.8
8	6300	2000	200	28.2	6100	9.9	288.2	2600	9.5	108.1	3700	9.9	159.9	180.1
9	6300	2000	200	33.4	6100	9.2	274.8	2600	8.9	101.0	3700	9.2	148.9	173.8
10	6300	2000	0	0.0	6300	7.3	201.4	2600	7.3	83.1	3700	7.3	118.3	118.3
						Uranium Extracted from Great Miami Aquifer (lbs)	4707.6	Uranium Injected (lbs)		401.6	Uranium Removed from Great Miami Aquifer (lbs)			4306.0

[a]Calculated from residual uranium concentrations in injected water.

4.2.4.4 Summary of Significant Design Issues

Similar to the 15-year scenario, in order to implement the 10-year scenario, the following design issues need to be addressed:

- Increased complexities of the extraction piping networks due to a larger number of wells
- Piping network for the two groundwater injection systems
- Converting extraction wells to injection wells
- Maintaining long-term efficiency of the injection wells
- Access for the four new off-property vertical extraction wells
- Effects from potential delays in the soil remediation schedule.

4.2.5 A Potential 7.5-Year Scenario

The intended cleanup time of this scenario (i.e., 7.5 years) is shorter than the soil and source-area remediation time frame under the Ten Year Plan. Therefore, horizontal wells were evaluated as a means to reach and pump directly from groundwater hot spots before the completion of surface remediation. Horizontal wells can be located outside a soil remediation area and then extend underground into targeted groundwater plumes beneath the remediation area. Because no horizontal wells have been used previously at the FEMP, their feasibility for groundwater remediation was evaluated. Major issues and the information collected during this evaluation are summarized in Appendix B. The general conclusion is that horizontal well technologies can be successful in certain applications at the FEMP as long as appropriate design, installation, and maintenance procedures are employed.

Under this scenario, horizontal wells are required in the inactive flyash pile, waste pit and former production areas to achieve the targeted cleanup time of 7.5 years. Horizontal wells along the fence line, instead of the off-property vertical extraction wells used in the previous three scenarios, are also incorporated in this scenario for the enhanced remediation of the off-property South Plume. This was considered in this scenario if off-property surface access becomes a problem and vertical wells cannot be used.

4.2.5.1 Wellfield Pattern

The wellfield pattern for the 7.5-year scenario is shown in Figure 4-4. Eight horizontal wells were used in both the excavated and off-property areas. Although not specifically modeled as horizontal wells, the discharges from the ten vertical wells in the waste pit area and two vertical wells in the Plant 6 area were combined for system performance calculations as if the discharges came from three

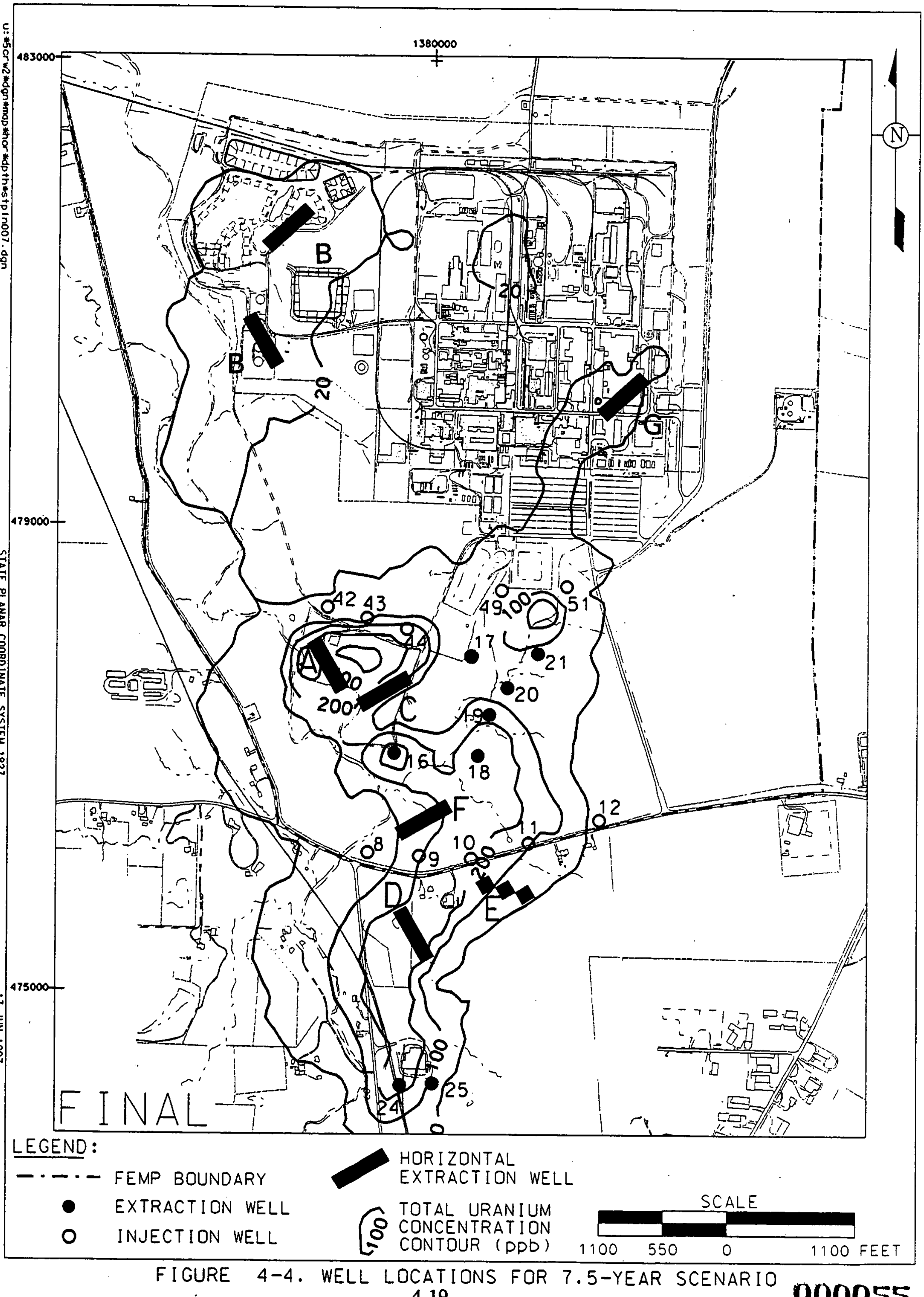


FIGURE 4-4. WELL LOCATIONS FOR 7.5-YEAR SCENARIO

separate horizontal wells, two in the waste pit area and one in the Plant 6 area (See Appendix A). These three horizontal wells were assumed to have the same performance as the vertical wells in these areas from the 10-year scenario except for the earlier start time for the horizontal wells. Vertical wells, other than the existing South Plume wells, are only used in the SSOD area for extraction; groundwater injection operations also still use vertical wells.

Length, locations, orientations, and extraction rates of these horizontal wells were determined using a multistep modeling approach. A pipe flow model (i.e., Fathom, see Appendix B) was first used to determine the inflow rate distributions along various horizontal well-screen designs. Factors considered in this analysis included well diameter, length and depth, number of pumps, and aquifer response to pumping. Each of the estimated inflow rate distributions was then converted into a series of accumulated inflows in the SWIFT model grid blocks where the horizontal well was located.

Iterative SWIFT model simulations were then conducted to predict contaminant transport during the remediation and to finalize the conceptual layout of each horizontal well design. Because a horizontal well can be installed by either horizontal directional drilling or Ranney technology, the advantages and disadvantages of these two approaches were evaluated to select the appropriate installation method.

The major advantages of using horizontal directional drilling include the capability to install much longer wells (i.e., with more than a 350-foot-long horizontal section) and continuous wells (i.e., wells with both ends open to the ground surface). The expected cost of directional drilling is lower than the Ranney approach. However, in order to facilitate the desired high pumping capacity (i.e., 300- to 900 gpm), larger well diameters will need to be installed than is typically done in directional drilling applications. Another potential problem associated with the directional drilling is that it is often difficult to properly develop the well (i.e., to remove fine materials from the formation and the residual drilling mud used during the drilling process). There is also no assurance that, even with adequate well-screen diameters, effective well maintenance can be performed due to the curvature of the well which may preclude the use of appropriate well-cleaning devices.

Ranney collector wells have a better chance to obtain the high pumping capacities because no drilling mud is required during installation and larger or multiple pumps can be installed in the 9- to 16-foot caisson. Ranney wells can also have multiple lateral drains in a single caisson. In a Ranney well, access to the well-screens is easily made in the caisson so that proper well-cleaning equipment can be used to rehabilitate the well-screens, if required. However, significant amounts of soil need to be excavated and disposed of during installation. The required length of the horizontal well specified in Figure 4-4 is much longer than is typically done in Ranney well applications (i.e., up to 350 feet). Installation of the large caisson and associated health and safety requirements will result in much higher costs for Ranney wells than for wells installed by directional drilling.

Based on the advantages, disadvantages, and limitations of the two horizontal well installation technologies, the suitable installation technology for each horizontal well was selected. Directional drilling was selected to install the five continuous horizontal wells (i.e., can pump from the both ends) in the South Field, waste pit, and Plant 6 areas. The main reason for this selection was the contaminated soil in these areas which will preclude the Ranney approach. Due to the potentially lower achievable pumping rate in each well, additional horizontal wells can be installed in these areas to ensure the desired overall extraction rates, if deemed necessary. The Ranney approach was selected for installing the three horizontal wells in the South Plume/South Field area, because the overburden is considered clean and higher pumping rates are required in this area. Although these selections do not affect the estimated performance measures, they will be reflected in the estimated cost of this scenario.

4.2.5.2 Extraction/Injection Pumping Rate Schedule

The extraction/injection schedule used to achieve the 7.5-year cleanup is presented in Table 4-7. In general, the extraction rate of a horizontal well is equivalent to the total extraction rate of a group of vertical wells used in the previous scenarios. However, the horizontal wells can be operated before completion of soil remediation. The use of horizontal wells also enables a longer section of well-screen to be installed (for the same overall extraction rate) to lower the entrance velocities through the well-screen and reduce the head losses, which results in a lower plugging rate and lower maintenance requirements.

4.2.5.3 Predicted Performance

System performance measures including years of groundwater treatment, extracted groundwater concentrations to and by-passing the treatment plant, blended outfall concentrations, and uranium

TABLE 4-7

EXTRACTION/INJECTION SCHEDULE USED FOR 7.5-YEAR SCENARIO

		Pumping Rates (gpm) (+) = Pumped (-) = Injected		
Location	Well No.	Years 0 to 2	Years 3 to 5	Years 6 to 7.5
Waste pits	B1	0	500	0
Waste pits	B2	0	500	0
Totals		0	1000	0
Plant 6	G1	0	500	0
Totals		0	500	0
Fenceline injection wells	8	0	-200	-200
Fenceline injection wells	9	0	-200	-200
Fenceline injection wells	10	0	-200	-200
Fenceline injection wells	11	0	-200	-200
Fenceline injection wells	12	0	-200	-200
Totals		0	-1000	-1000
South Field	13	0	0	0
South Field	14	0	0	0
South Field	15	0	0	0
South Field	16	0	200	200
South Field	17	0	0	0
South Field	18	0	100	200
South Field	19	0	100	200
South Field	20	0	100	200
South Field	21	0	100	200
Totals		0	600	600
South Field injection wells	42	0	-200	-200
South Field injection wells	43	0	-200	-200
South Field injection wells	44	0	-200	-200
South Field injection wells	49	0	-200	-200
South Field injection wells	51	0	-200	-200
Totals		0	-1000	-1000
South Plume	24	300	300	300
South Plume	25	300	300	300
South Plume	26	400	0	0
South Plume	27	400	0	0
South Plume optimization	1	0	0	0
South Plume optimization	2N	0	0	0
South Plume optimization	3N	0	0	0
South Plume optimization	KN	0	0	0
Totals		1400	600	600
South Field horizontal	A1	0	150	150
South Field horizontal	A2	0	100	100
South Field horizontal	A3	0	100	100
South Field horizontal	A4	0	150	150
Totals		0	500	500
South Field horizontal	C1	0	150	150
South Field horizontal	C2	0	100	100
South Field horizontal	C3	0	100	100
South Field horizontal	C4	0	150	150
Totals		0	500	500

TABLE 4-7
(Continued)

Location	Well No.	Pumping Rates (gpm) (+) = Pumped (-) = Injected Years 0 to 2	Years 3 to 5	Years 6 to 7.5
South Field horizontal	F1	0	160	160
South Field horizontal	F2	0	100	100
South Field horizontal	F3	0	80	80
South Field horizontal	F4	0	60	60
Totals		0	400	400
South Plume horizontal	D1	0	360	360
South Plume horizontal	D2	0	225	225
South Plume horizontal	D3	0	180	180
South Plume horizontal	D4	0	135	135
Totals		0	900	900
South Plume horizontal	E1	0	150	150
South Plume horizontal	E2	0	90	90
South Plume horizontal	E3	0	60	60
Totals		0	300	300
Total pumping		1400	5300	3800
Total injecting		0	-2000	-2000
Net aquifer extraction		1400	3300	1800

mass removed are listed in Table 4-8. Due to the higher extraction rate directly from groundwater hot spots and operation of both injection systems, significantly more groundwater treatment capacity (i.e., an additional 1000 gpm) will be required for this scenario.

4.2.5.4 Summary of Significant Design Issues

In order to implement the 7.5-year scenario using horizontal wells, the following design issues need to be addressed:

- Piping network for the two groundwater injection systems
- Maintaining long-term efficiency of the injection wells
- Difficulties associated with horizontal well installation
- Additional treatment capacity needed.

4.3 COMPARISONS AND SELECTION

Based on the specifications of the evaluated scenarios and predicted performance measures summarized in Section 3.0, this section compares the cost-effectiveness and potential risk/uncertainty for implementing the evaluated remediation scenarios. Based on the comparisons, recommendations for the new baseline groundwater remediation strategy at the FEMP are provided.

4.3.1 Relative Cost Estimation

All four groundwater remediation scenarios developed in this study can satisfy all the commitments and constraints when sufficient groundwater treatment capacity is available. A ranking based on relative overall costs of all the evaluated remediation scenarios is required in order to determine the optimal cost-effectiveness. The costs for additional treatment capacity over 2000 gpm are also included for two of the scenarios (i.e., the 25-year and 7.5-year scenarios). It needs to be noted that for both of these scenarios, the additional capacity is greater than the expanded capacity commitment contained in the Operable Unit 5 ROD.

4.3.1.1 Estimated Relative Component Costs

Relative costs of major system components such as different types of wells, well O&M, groundwater treatment module, groundwater treatment operation, and groundwater monitoring activities are listed in Table 4-9. The relative costs are presented as ratios to the cost for design and construction of a typical on-property vertical extraction well and associated pump and piping (i.e., about $500,000).

TABLE 4-8

SYSTEM PERFORMANCE MEASURES FOR 7.5-YEAR SCENARIO

Year	Total Water Pumped (gpm)	Treatment Capacity (gpm)	Water to Treatment (gpm)	Concentration to Treatment (ppb)	Water Not Treated (gpm)	Concentration Not Treated (ppb)	Uranium Extracted from Aquifer (lbs)	Injected Water (gpm)	Concentration of Injected Water (ppb)	Uranium Injected[a] (lbs)	Water Discharged (gpm)	Concentration of Discharge (ppb)	Uranium Discharged (lbs)	Uranium Removed from Aquifer (lbs)
1	1400	400	400	35.0	1000	35.0	214.5	0	N/A	0.0	1400	26.4	162.0	214.5
2	1400	850	850	32.2	550	32.2	197.5	0	N/A	0.0	1400	15.7	96.2	197.5
3	5300	2000	1800	121.7	3500	35.8	1506.7	2000	8.1	70.7	3300	35.8	516.4	1436.0
4	5300	2000	1800	89.7	3500	31.6	1190.4	2000	7.7	67.0	3300	31.6	455.8	1123.4
5	5300	2000	1800	69.7	3500	28.3	983.1	2000	7.3	64.2	3300	28.3	409.3	918.9
6	3800	2000	1800	57.4	2000	28.8	703.5	2000	7.4	64.6	1800	28.8	226.5	638.9
7	3800	2000	1800	49.5	2000	25.2	610.7	2000	7.0	61.5	1800	25.2	198.7	549.2
8	3800	2000	0	0.0	3800	3.6	59.5	2000	3.6	31.3	1800	3.6	28.2	28.2

Total U

Uranium Extracted from Great Miami Aquifer (lbs)	5465.8	Uranium Injected (lbs)	359.2	Uranium Removed from Great Miami Aquifer (lbs)	5106.6

[a]Calculated from residual uranium concentrations in injected water.

TABLE 4-9

ESTIMATED RELATIVE UNIT COSTS OF MAJOR COMPONENTS

Components	Relative Costs
1 On-property vertical extraction well (including pump and piping)	1 ($500,000)[a]
1 Off-property vertical extraction well (including condemnation, pump and piping)	2
1 Vertical injection well (including piping)	0.75
1 Horizontal extraction well (by directional drilling, including pump and piping)	4.5 - 6
1 Ranney well (including pump and piping)	7.5 - 10
1 Additional horizonal section from a Ranney well (including pump and piping)	4 - 6
O&M per vertical extraction well per year (Years 0-10/11-)	0.07/0.1
O&M per horizonal extraction well per year (Years 0-10/11-)	0.14/0.2
O&M per injection well per year (Years 0-10/11-)	0.035/0.05
Expansion of groundwater treatment capacity to 2000 gpm	7.5
1 250-gpm mobile groundwater treatment module	3
Groundwater treatment per year (Years 0-10/11-)	6/8
General groundwater monitoring and reporting per year (Years 0-10/11-)	2/3

[a] Estimating unit

These relative costs were estimated based on costs of existing systems and design packages at the FEMP, EPA documents, and information from vendors and represent DOE's best estimate of the cost of each of the major system components. The component-specific sources of information for unit cost estimation and the associated uncertainty are summarized in Table C-1 of Appendix C. Uncertainties associated with the estimated unit costs are presented in three categories (i.e., low, moderate, and high).

Due to higher uncertainties associated with directional drilling and Ranney well installations, the potential ranges of relative costs for these wells were estimated. During groundwater remediation relative unit costs for noncapital components are expected to increase with time. The reasons for the increases include older equipment and a heavier share of administration costs assigned to the Aquifer Restoration Project when the number of other ongoing remediation projects at the FEMP gradually decreases. Therefore, the relative unit costs for four components (i.e., O&M costs for extraction and injection wells, groundwater treatment, and groundwater monitoring) are estimated separately for the first 10 years and beyond.

4.3.1.2 Scenario-Specific Relative Cost

Using the relative unit costs listed in Table 4-9 as well as component specifications, cleanup times, and required groundwater treatment capacities summarized in Section 3.0, the scenario-specific relative overall costs (without inflation) are listed in Table 4-10 (in units of $500,000). To simplify the cost estimation process, the effects of installation timing, escalation, and potential interest savings are not considered. The potential impacts from these simplifying assumptions on the relative cost are considered small given the shorter durations of the groundwater remediation scenarios. Such simplifying assumptions are also consistent with DOE's programmatic evaluations of the long-term cost savings that may accompany implementation of the Ten Year Vision. As shown in Table 4-10, the annual groundwater treatment cost is assumed to be independent of treatment flow rates. More details of the cost calculations are included in Appendix C. Although all the simplifications are considered reasonable, these cost estimates are only intended for ranking and strategy selection purposes instead of detailed budgeting purposes.

TABLE 4-10

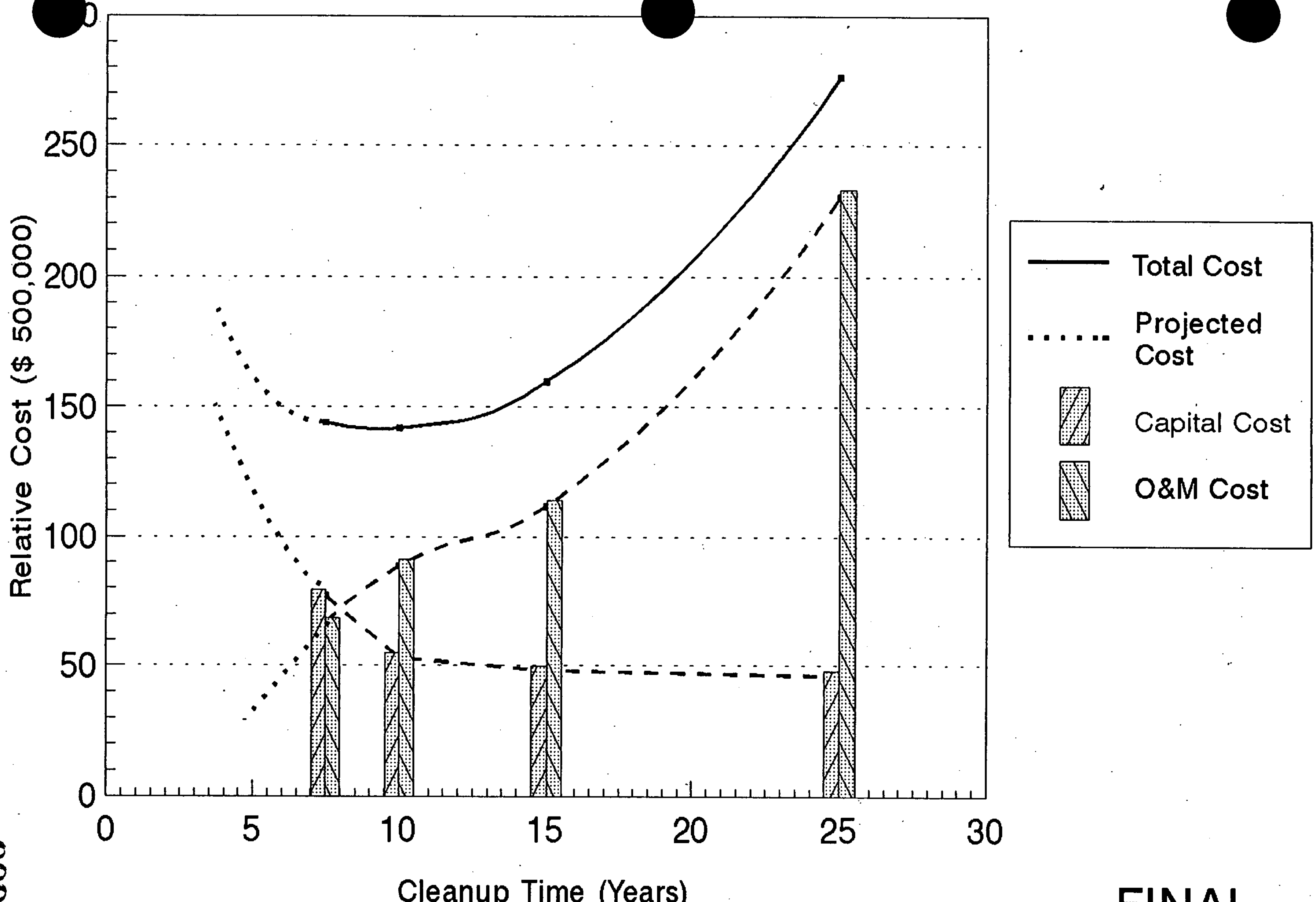
SUMMARY OF THE ESTIMATED SCENARIO-SPECIFIC RELATIVE

Cost	Remediation Scenario			
	25-Year	15-Year	10-Year	7.5-Year
Capital				
Well, pump, piping	35	40	45	50 - 65
Treatment	15	9	7	20
Well operation & maintenance	25	17	14	10
Treatment operation & maintenance	140	60	54	45
Monitoring/Reporting	65	35	20	15
Total	280	160	140	140 - 155

[a]Estimating unit is $500,000

The number of significant digits used in the cost calculations presented in Appendix C may be misleading regarding the expected accuracy of the overall cost estimates. Due to the inherent uncertainty of the relative unit costs (see Table C-1 of Appendix C), the scenario-specific overall costs may be rounded to 280, 160, 140, and 140-155 units for the 25-Year, 15-Year, 10-Year, and 7.5-Year Scenarios, respectively. These rounded relative overall costs only reflect the uncertainty associated with the unit costs. Potential uncertainty of the overall remediation cost due to uncertainty of the actual cleanup time achievable by the selected baseline remedial strategy is evaluated in Section 5.3.2 and Appendix F.

Figure 4-5 shows the relationship between cleanup time and relative costs for the four evaluated scenarios. Capital and O&M costs (including well O&M, treatment O&M and monitoring/reporting) are plotted separately. An average capital cost for well, pump, and piping in the 7.5-year scenario (i.e., 57.5) is used in the figure. The cost trend for scenarios with cleanup times less than 7.5 years is shown by the dashed lines from 5 years to the first data point at 7.5 years. As shown in the figure, a longer cleanup time means lower capital but higher O&M costs; a shorter cleanup time means higher capital but lower O&M costs; and a cleanup time around 10 years results in the optimal overall remediation cost. In the optimal-cost scenario, the capital and O&M portions of the overall



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FINAL

FIGURE 4-5. CONCEPTUAL COST COMPARISON

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remediation costs are about 40 and 60 percent, respectively. When the O&M or the capital cost exceeds 40 percent, the overall remediation cost becomes higher than the optimal cost. It is important to note that the cost increases are more significant in scenarios with longer cleanup times. Table 4-11 summarizes the present worth analysis (see Appendix C) of the four scenarios with three assumed discount rates. The 2.8% rate is the rate used in the Operable Unit 5 FS cost estimation. As shown in Table 4-11, the 10-year scenario also has the lowest present worth cost (in dollar values) among the scenarios.

TABLE 4-11

SUMMARY OF THE PRESENT WORTH ANALYSIS
(Present Worth Costs In Millions)

Discount Rate	25-Year Scenario	15-Year Scenario	10-Year Scenario	7.5-Year Scenario
0.0 %	140	80	70	70 - 75
2.8 %	110	70	65	65 - 72
5.0 %	90	65	60	62 - 70

4.3.2 Implementation Risk and Uncertainty

In addition to the cost, other factors that may affect the implementability of a groundwater remediation scenario need to be understood when selecting the final remedial strategy. Minimizing the selected strategy's unavoidable implementation risks and uncertainties should be emphasized during the design process. When the selected strategy cannot be implemented due to unforeseen reasons, an alternative should be readily available for implementation. In general, the four remediation scenarios evaluated provide a sufficient range of potentially implementable alternatives that satisfy all the commitments.

4.3.2.1 Source-Area Remediation Schedule

Because the 10-year site-wide remediation plan is very aggressive, the possibility of significant delays in the schedule is considered moderate (i.e., 50/50). Under this situation the scenarios which rely on additional vertical extraction wells inside the excavated zones (i.e., the 15-year and 10-year scenarios) may not achieve the predicted cleanup times and become impractical. Implementabilities and performances of the 25-year and 7.5-year scenarios are less sensitive to the soil remediation schedule because no wells need to be installed in the excavation zones.

4.3.2.2 Treatment Capacity and Efficiency

Sufficient groundwater treatment capacity needs to be available before certain proposed groundwater extraction and/or injection rates can be implemented. This is especially important during the first few years when large volumes of contaminated groundwater with higher concentrations will be extracted. The treated groundwater concentrations also need to be sufficiently low (as assumed in the modeling) so the projected treatment capacity is sufficient for maintaining acceptable outfall concentrations and for supplying source water for injection wells.

During groundwater remediation, if the treatment capacity and/or efficiency are significantly lower than currently expected, the extraction/injection pumping rate schedules may need to be reduced in order to maintain low outfall concentrations. These modifications will result in longer cleanup and treatment times than originally predicted. Alternatively, additional treatment capacity would need to be provided.

The possibility of a significant schedule delay for bringing the expanded AWWT capacity of 1800 gpm on-line is low. With the expansion of the AWWT facility on-line, the total effective capacity for treating groundwater will be assumed to be 2000 gpm. However, the chance of getting any additional capacity by adding mobile treatment modules is also very low. A potential compromise is to use capacity freed up from surface water treatment for groundwater treatment during drier seasons. However, this will require schedule changes and lower extraction and/or injection rates for remediation scenarios which require higher treatment capacities. The possibility of lower treatment efficiency, resulting in higher treated groundwater concentrations (> 5 ppb), is currently considered moderate.

4.3.2.3 Well Design and Installation

The overall performance of any groundwater remediation system is highly dependent on the proper design, installation and operation of all the required extraction and injection wells. Risk and uncertainty related to design and installation of the three types of wells evaluated in this study are summarized below. In general, other than the vertical extraction wells, there are many lessons and issues which need to be learned and resolved for the injection wells and the horizontal extraction wells.

- Vertical Extraction Well - Sufficient experience with vertical extraction well design and installation exists at the FEMP. Hydrogeological conditions at proposed well locations that may affect installation have been properly characterized. However, uncertainties in groundwater contaminant concentrations and plume thicknesses at these locations still remain and may not be confirmed until the wells are installed. Installation schedules for wells in areas requiring soil remediation will depend on the actual completion date of the remediation.

- Injection Well - Design and maintenance procedures for an injection well with a long-term efficiency have not been completed. Injection-specific hydraulic conditions as well as plugging need to be considered during the design process. The currently assumed groundwater injection rates may not be achievable if the injection well is not properly designed and maintained.

- Horizonal Extraction Well - Although the potential benefits of horizontal wells are very significant, the costs and risks associated with them are also very high. Design and installation of a horizontal well is considerably more complicated than a vertical well. In order to achieve high pumping capacity and long operational life, more detailed analysis of the geological conditions and even pilot-scale field tests may be required to properly design the horizontal wells based on the site-specific conditions. A much higher chance of installation problems with a horizontal well can also be expected. An insufficient capacity and/or a short operational life may result from improper installation procedures.

4.3.2.4 Operation and Maintenance

A perfectly designed and installed hardware system does not automatically result in successful groundwater remediation. Proper O&M of the system are as important as the hardware system. The role and contents of an Operations and Maintenance Plan for the aquifer restoration system are being defined (as Task 2 of the Operable Unit 5 RD Work Plan). This plan will address all the important issues considered and resolutions obtained during the design and installation processes which may affect the system's performance. System operation, monitoring, adjustment, and maintenance needs to be closely integrated. In order to ensure the success of aquifer restoration, guidelines for the key activities listed below need to be defined.

- System Performance Monitoring - Aquifer, wellhead, and outfall contaminant concentrations as well as the injection and treatment efficiencies need to be monitored. All the decisions to be made during groundwater remediation will rely on these monitoring results. Frequency, locations, and parameters for performance monitoring need to be properly selected.

- Treatment Decision - Because treatment capacity is limited, extracted groundwater from the right wells needs to be treated in order to maintain the acceptable outfall concentrations; wells showing higher concentrations should obviously have priority for treatment. Available capacity freed up from surface or other remediation- generated water treatments should also be used to treat groundwater when possible.

- Groundwater Injection - Only treated groundwater and extracted groundwater with wellhead concentrations less than 20 ppb can be injected. Full benefits of groundwater injection can only be achieved by obtaining a sufficient amount of acceptable water and maintaining high hydraulic efficiency of the injection wells. In order to operate within the maximum allowable net extraction rate, groundwater extraction needs to be throttled down when the actual injection rate is lower than currently assumed. Extracted groundwater with wellhead concentrations less than 20 ppb may also need to be treated for iron removal before injection, in order to prevent problems associated with iron precipitation in the injection wells. This groundwater treatment need was not considered during the preliminary evaluation of the four potential scenarios.

- System Adjustment - The well pattern and extraction/injection pumping rate schedule specified in the remedial strategy are developed by conducting groundwater model simulations. Although groundwater models are the only tool available for developing the remedial strategy, it is important to note that all groundwater models have limitations when simulating the real world conditions. Assumptions and simplifications regarding the modeled physical and chemical processes may lead to inaccurate model predictions. Therefore, operation of the remediation system should have sufficient flexibility in order to handle unexpected conditions. Frequent adjustments of the extraction/injection pumping rate schedule, monitoring of performance, frequency, locations and treatment decisions may be necessary to maintain the desired system performance.

- System Maintenance and Rehabilitation - All hardware components in the groundwater remediation system will require routine maintenance in order to prevent their deterioration. Extraction and injection wells may need periodic rehabilitation in order to recover their efficiency.

4.3.2.5 Geochemical Conditions

On average the assumed uranium K_d values during groundwater remediation are considered realistic. Potentially the uranium K_d value may further increase above 17.8 L/kg resulting in lower uranium mobility. However, the estimated groundwater cleanup time will not change significantly due to lower groundwater concentrations because less uranium mass will be desorbed under higher K_d values. Timing of the transition from lower K_d value to higher K_d values should be closely monitored by evaluating mass removal efficiencies in the extraction wells. This timing is important for determining when to start groundwater injection north of the South Field in the 15- and 10-year scenarios.

As a critical component in all the groundwater remediation scenarios evaluated in this report, the feasibility of groundwater injection remains to be confirmed. Although water can be injected into the aquifer without much initial resistance, the problem of iron precipitation and subsequent plugging of the well-screen as described in the draft South Field Injection Test Report (DOE 1995d) needs to be resolved. An O&M procedure that can ensure long-term efficiency and injectivity of the injection wells is necessary. This procedure may include additional pretreatment for injection water and/or periodic rehabilitation of the injection wells. The second short-term injection test which used treated groundwater showed promising results.

4.3.3 Selected Preliminary Baseline Strategy

Based on the overall relative costs listed in Table 4-10 and risk/uncertainty information discussed in Section 4.3.2, the 10-year scenario is selected as the baseline groundwater remediation strategy for the remedial design process. The main reasons for this selection include:

- Overall relative cost is lower
- Capital cost for well installation is distributed over 7 years
- Piping network complexities due to the additional extraction wells are considered manageable
- No additional treatment capacity beyond the planned AWWT facility expansion is necessary
- The only higher risk and uncertainty associated with this scenario when compared to the other three scenarios is the soil remediation schedule.

The 7.5-year scenario was not recommended due to the significantly higher up-front capital cost (i.e., 70 to 84 cost units) and high risks associated with horizontal well installation. However, if current funding projections or technical constraints were to indicate that the source-area remediation will be delayed for more than 5 years and sufficient groundwater funding is available, then the 7.5-year scenario could potentially be justified. As shown in Table 4-10, the estimated higher end of the overall cost of the 7.5-year scenario is slightly lower than that of the 15-year scenario. This indicates that when the groundwater cleanup time exceeds 15 years when using only vertical extraction wells, using horizontal wells to reduce the cleanup time becomes a much more competitive alternative. It is important to note that the window of opportunity for initiating the horizontal well alternative is within the next 2 years in order to realize any significant reductions of groundwater cleanup time and overall cost.

4.3.3.1 Modifications to The FS Strategy

When compared to the remedial strategy presented in the Operable Unit 5 FS Report, the following modifications have been included in the selected preliminary baseline strategy:

- Groundwater injection along the fence line and north of the South Field will be used to improve hydraulic performance of the remediation system. The fence line system (converted from Wells 8 through 12 in the FS Strategy) will start operation within 3 years while the upgradient system (5 new injection wells) will start at the end of the 7th year.
- Well 17 in the FS Strategy is moved to a new location north of the SSOD.
- Well 22 in the FS Strategy is reserved as a contingent well and its location will be selected during detail evaluation of the final strategy or remediation if determined necessary.
- Four additional off-property extraction wells and two of the existing South Plume wells will be used to optimize the South Plume Recovery Well System.
- Nine more vertical extraction wells in the inactive flyash pile, four more vertical extraction wells in the waste pit area, and one more vertical extraction well in the Plant 6 area will be installed and operated immediately following completion of local surface remediation.
- Three of the initial extraction wells around the inactive flyash pile will be converted into injection wells after the new extraction wells are installed.

Overall 46 wells (i.e., excluding Well 22) are included in the selected preliminary baseline strategy. The number of wells is 18 more than the number in the FS Strategy.

4.3.3.2 Groundwater Treatment Capacity

No groundwater treatment capacity above the planned 2000 gpm is necessary in the new baseline strategy. Appendix D describes the existing and currently planned treatment modules in the overall FEMP wastewater treatment system. The bulk of the dedicated groundwater treatment capacity will come from the AWWT facility expansion with its downrated capacity of 1500 gpm. Fifty percent of the downrated AWWT - Phase I capacity of 600 gpm (i.e., 300 gpm) will be dedicated to groundwater treatment. The interim AWWT (IAWWT) units will provide 350 gpm of dedicated groundwater treatment capacity annually. The South Plume interim treatment system is predicted to continue its good performance at 200 gpm for groundwater treatment. However, certain upgrades and/or modifications to the AWWT - Phase I and the IAWWT will be necessary. In summary, according to the current plan, over 2000 gpm of dedicated groundwater treatment capacity with an average effluent uranium concentration of 5 ppb will be available in 1998.

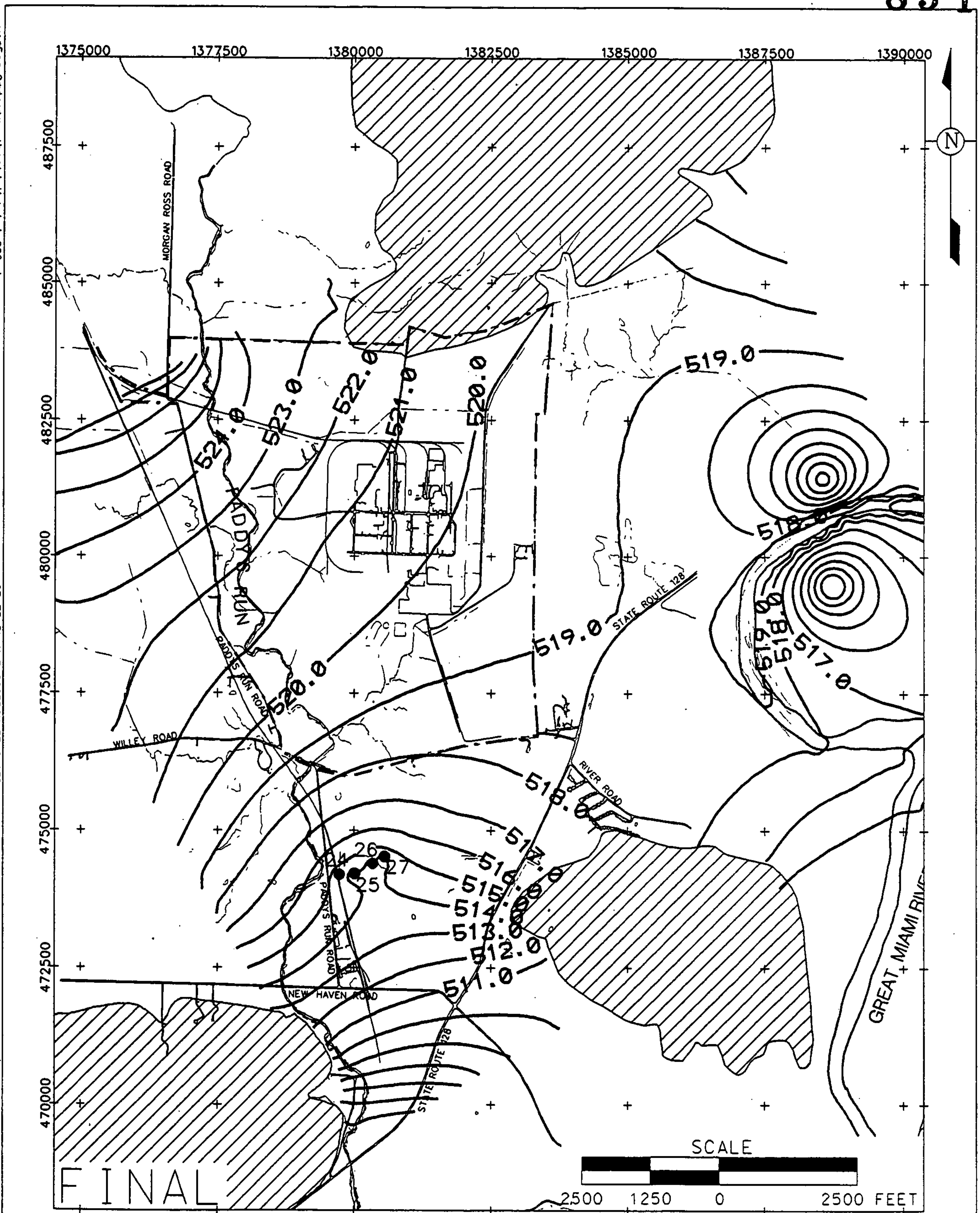
4.3.3.3 Predicted Hydraulic Impacts and Uranium Plumes

Figures 4-6 through 4-8 show the modeled groundwater flow patterns under the selected preliminary groundwater remediation strategy. Corresponding groundwater drawdown contours are shown in Figures 4-9 through 4-11. Groundwater and uranium capture zones with and without retardation resulting from this remedial strategy are presented in Figures 4-12 and 4-13. The particle tracks in Figures 4-12 and 4-13 were generated with STLINE (part of the SWIFT modeling software). Particles were seeded in model layers 1 and 2 and reverse tracked for each of the constant pumping periods in the modeling scenario in a reversed sequence. The initial STLINE run seeded particles at the pumping well locations and reverse tracked each particle for the last constant pumping rate interval. The final particle positions (horizontal and vertical) in the last constant pumping period were then used as input for the initial particle locations for the next to the last constant pumping period. This process was repeated in a reversed sequence through each of the constant pumping periods until the particles were at their initial locations before pumping began. The abrupt changes in particle tracks indicate the particle locations when nearby pumps were turned on for the next constant pumping interval. The projected uranium concentration contours are shown in Figures 4-14 through 4-16.

4.3.3.4 Aquifer Restoration Modules

In the preliminary baseline remedial strategy, the aquifer remediation would be accomplished through the six aquifer restoration modules shown on Figure 4-17. Each module consists of from 2 to 22 extraction and/or injection wells.

The existing South Plume extraction wells were installed and began operation in 1993 as part of a removal action to stop the further southward migration of the off property portion of the uranium plume. The module currently operates with four wells pumping at a combined rate of 1400 gallons per minute.



LEGEND:

FEMP BOUNDARY

EXTRACTION WELL

511.0 GROUNDWATER ELEVATION CONTOURS (FEET ABOVE msl)

FIGURE 4-6. GROUNDWATER ELEVATIONS FOR 10-YEAR SCENARIO YEARS 0 - 2

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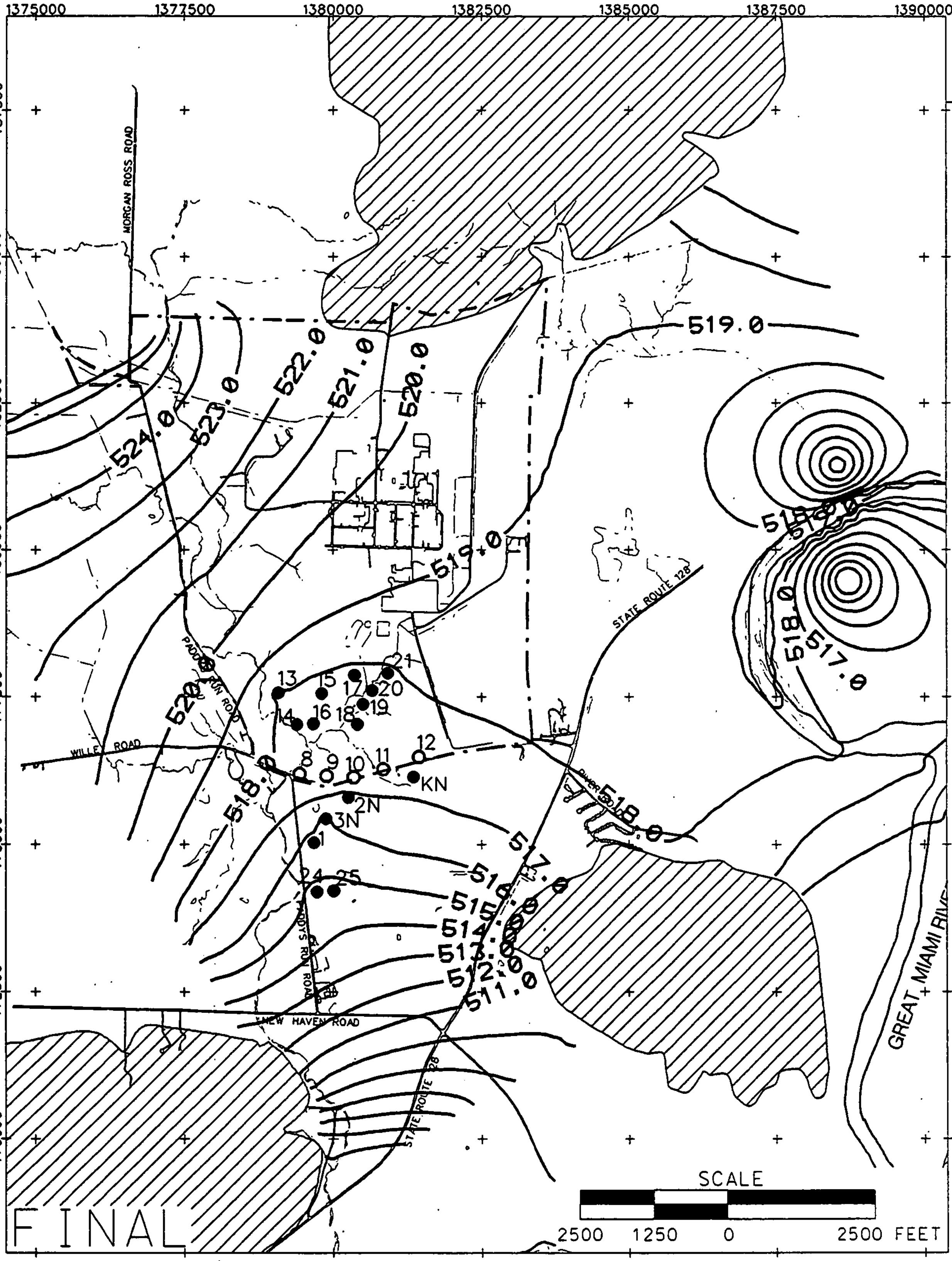

LEGEND:

- — · — · — FEMP BOUNDARY
- GROUNDWATER ELEVATION CONTOURS (FEET ABOVE msl) (511.0)
- ● EXTRACTION WELL
- ○ INJECTION WELL

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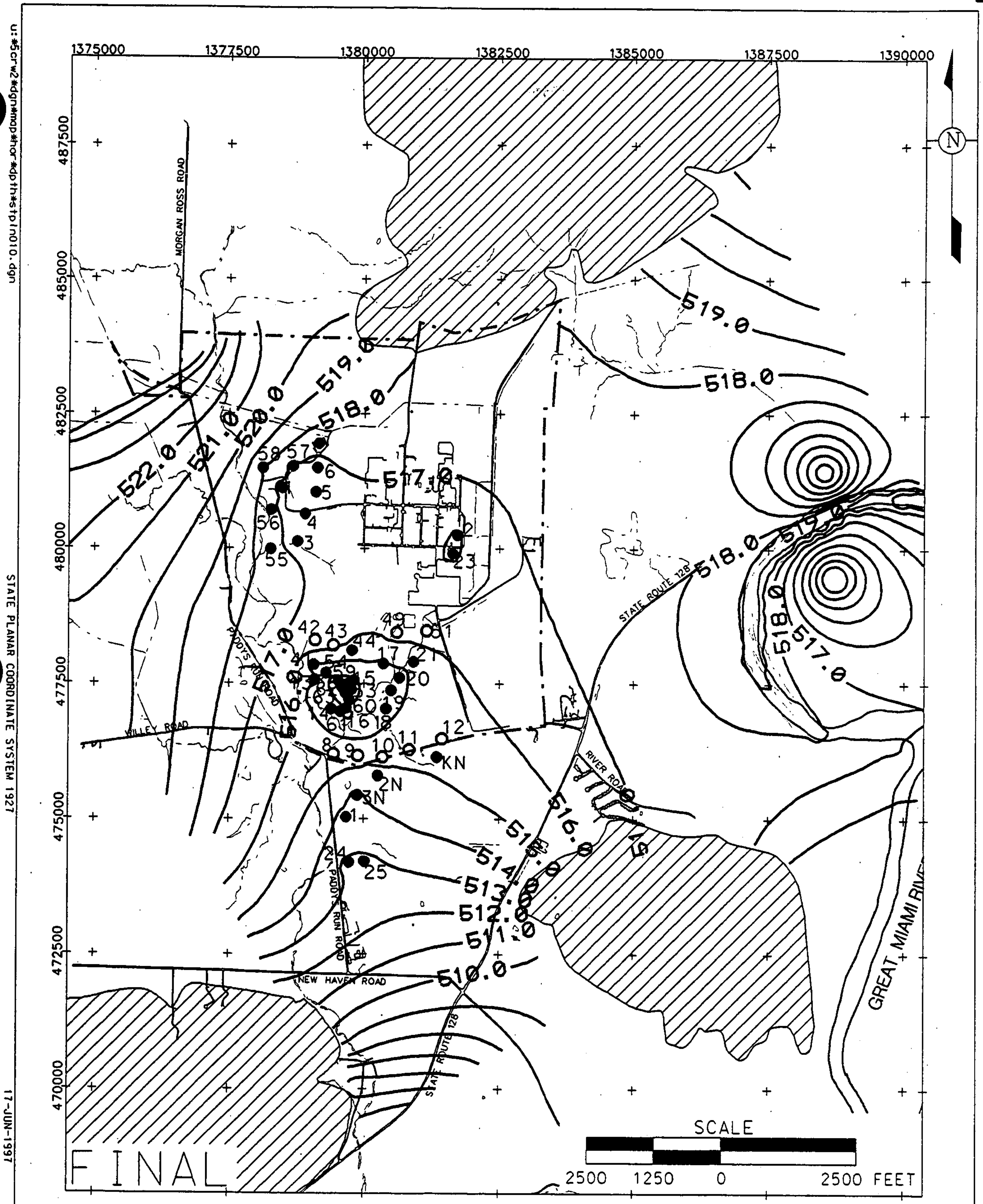
FIGURE 4-7. GROUNDWATER ELEVATIONS FOR 10-YEAR SCENARIO, YEARS 3 - 7



LEGEND:

FEMP BOUNDARY

GROUNDWATER ELEVATION CONTOURS (FEET ABOVE msl)

511.0

● EXTRACTION WELL

○ INJECTION WELL

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FIGURE 4-8. GROUNDWATER ELEVATIONS FOR 10-YEAR SCENARIO, YEARS 8 - 10

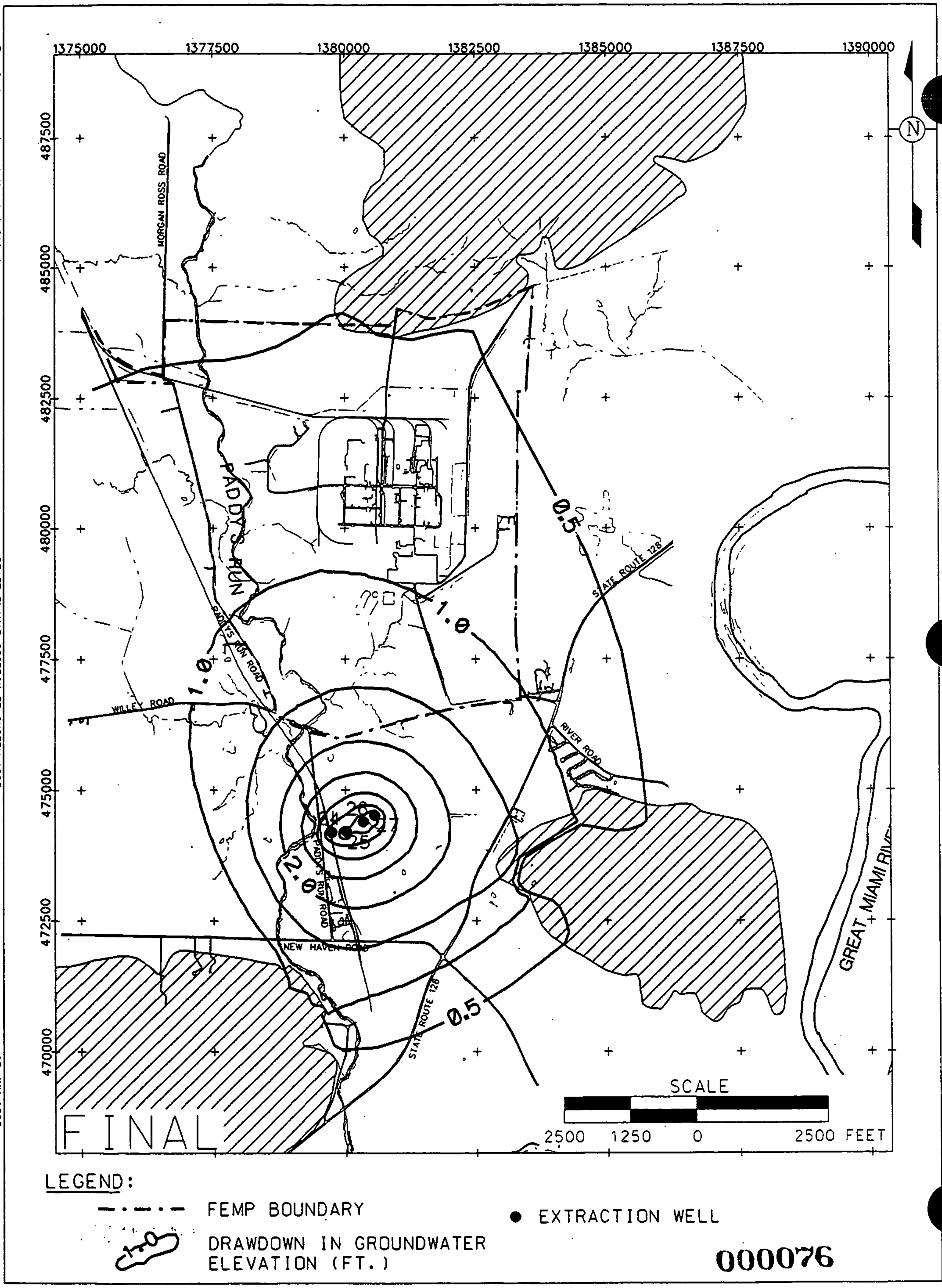

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FIGURE 4-9. DRAWDOWN CONTOURS, 10-YEAR SCENARIO, YEARS 0 - 2

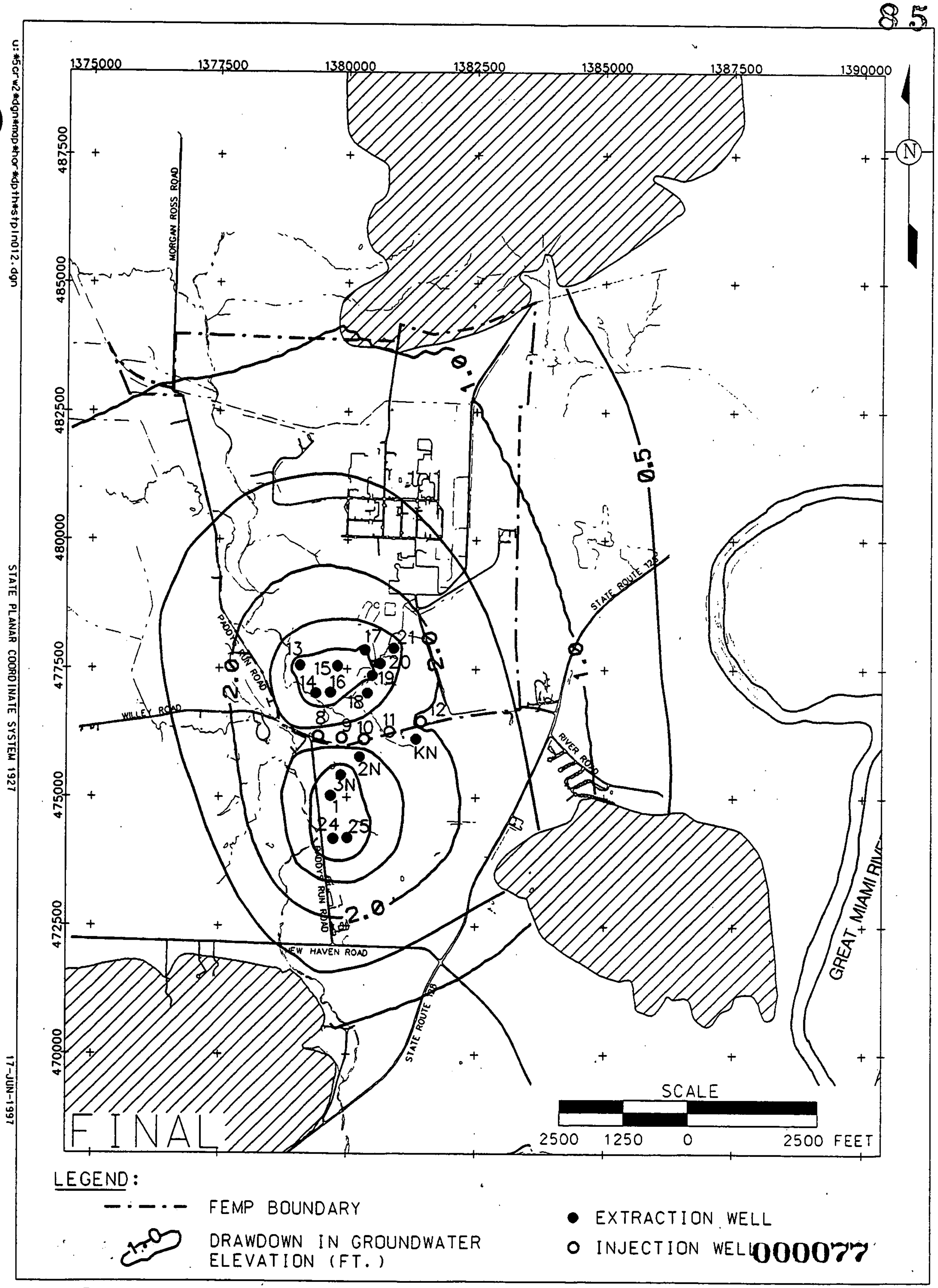

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FIGURE 4-10. DRAWDOWN CONTOURS, 10-YEAR SCENARIO, YEARS 3 - 7

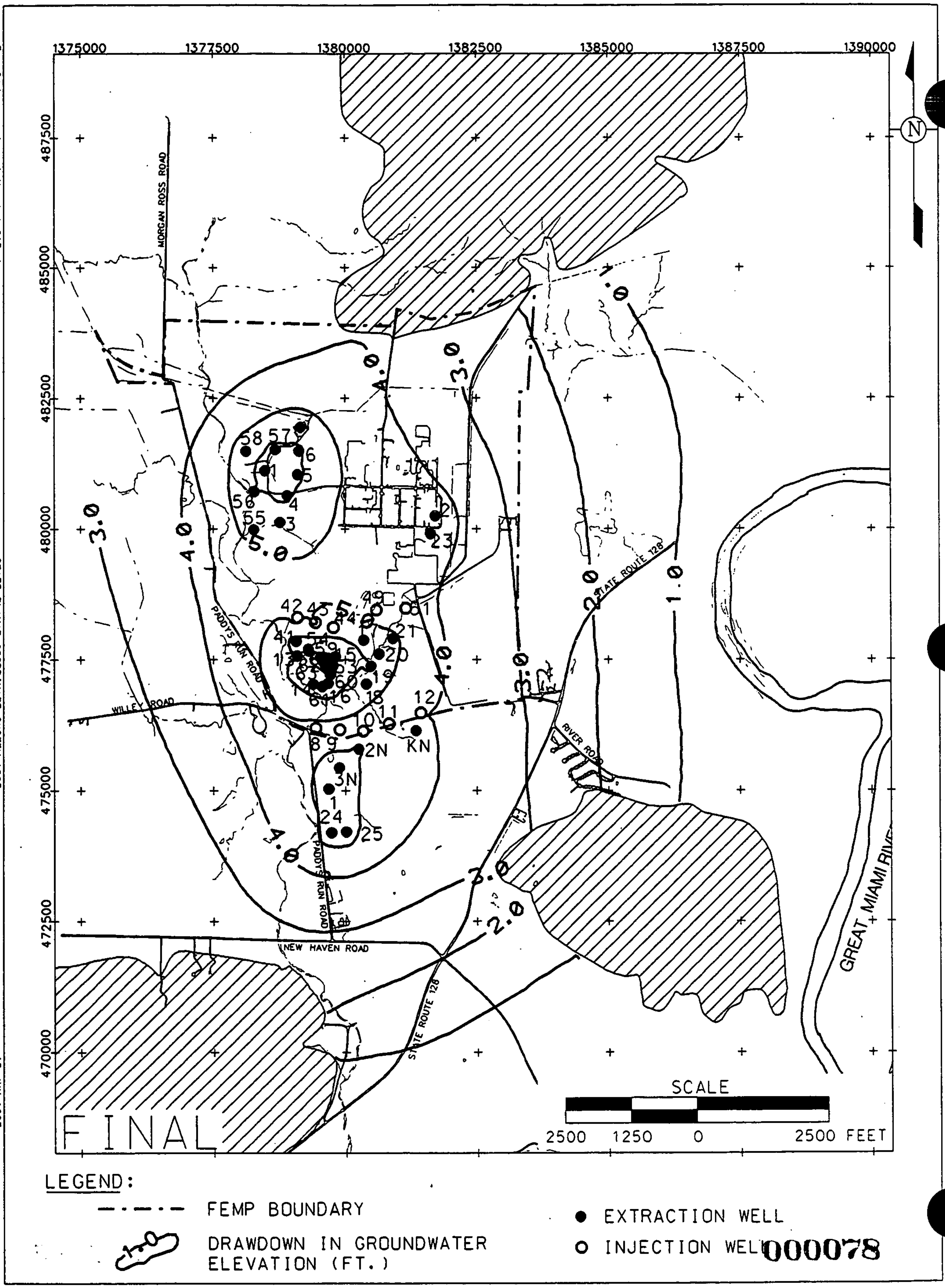

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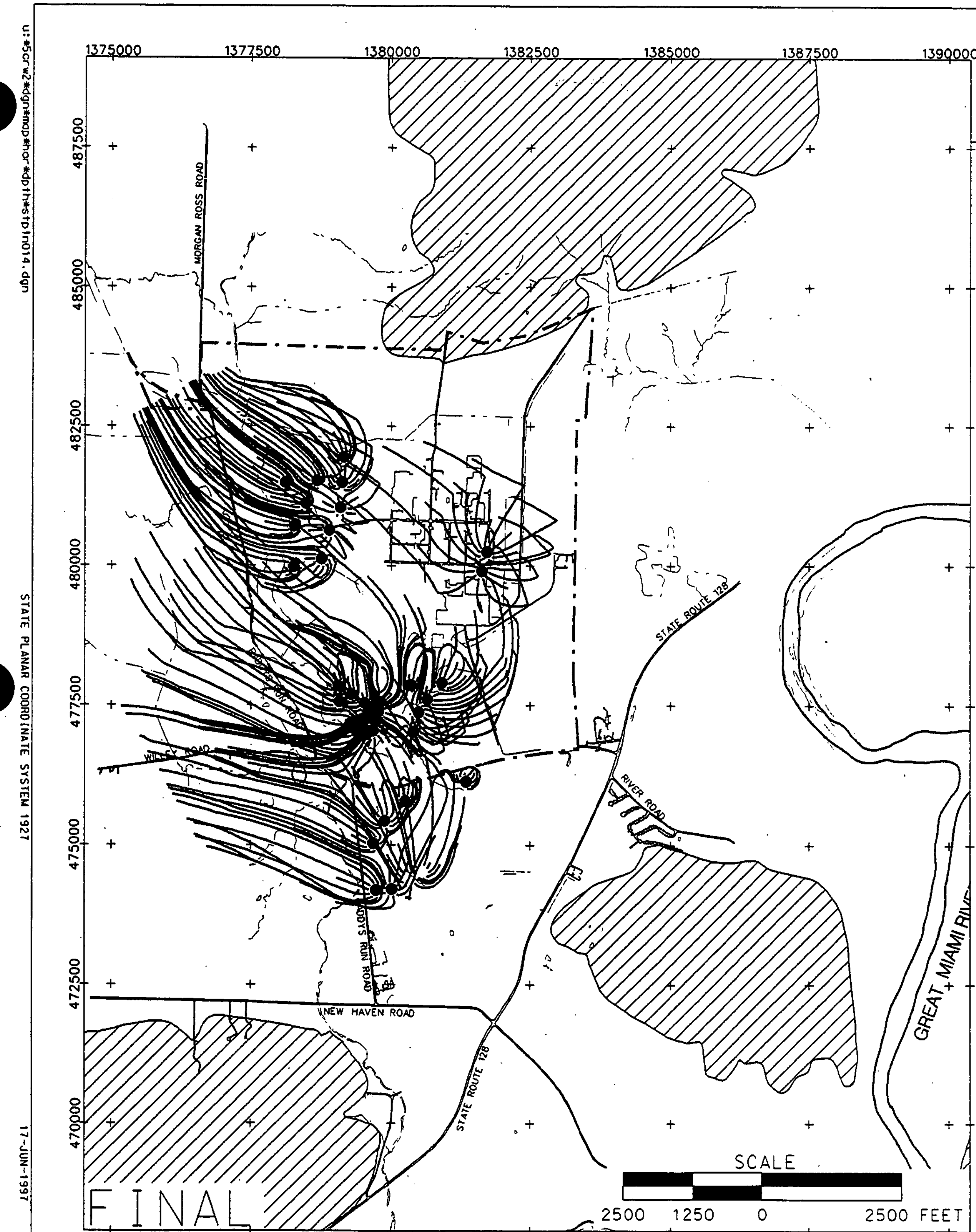
FIGURE 4-11. DRAWDOWN CONTOURS, 10-YEAR SCENARIO, YEARS 8 - 10



LEGEND:

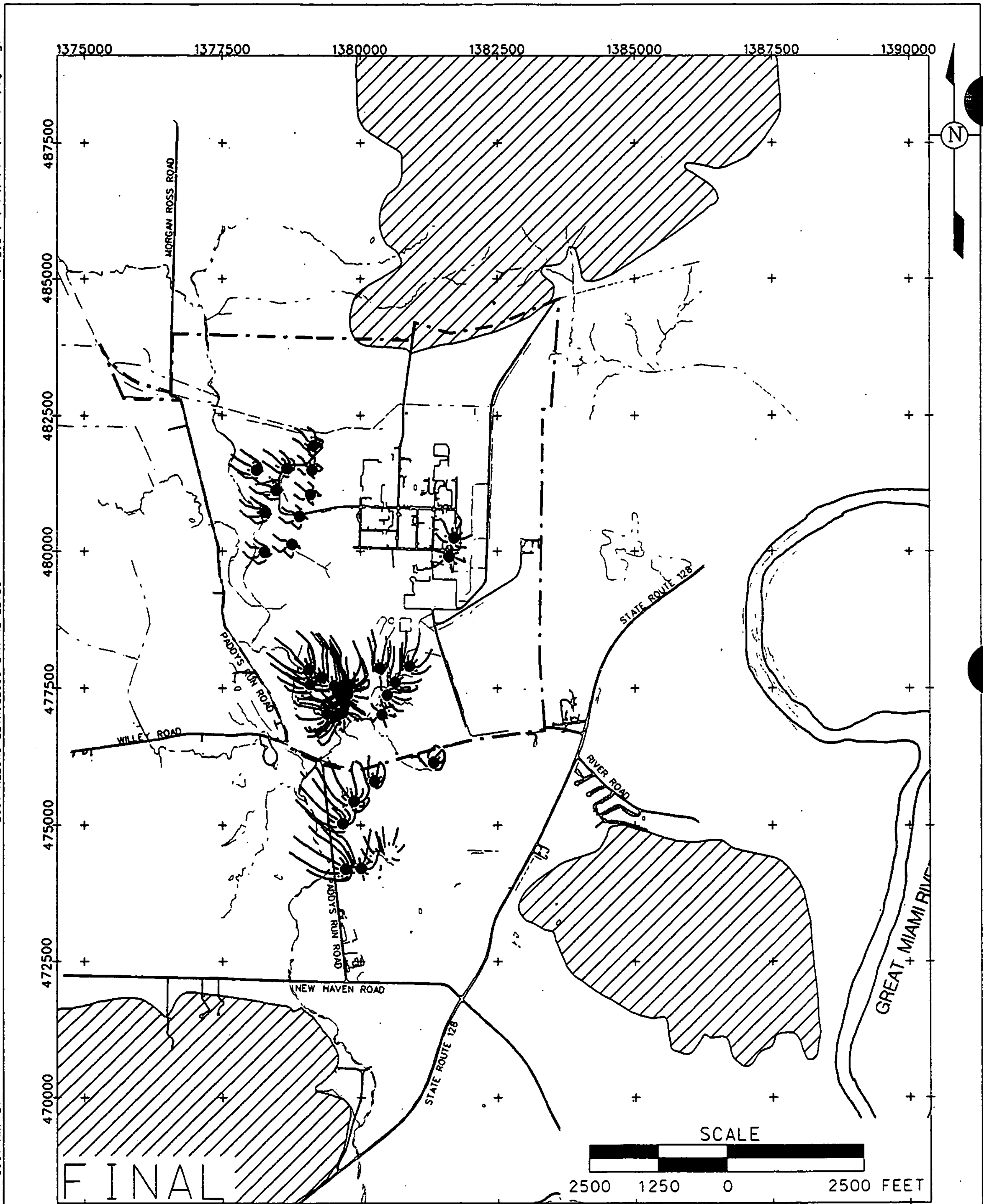
FEMP BOUNDARY

EXTRACTION WELL

10-YEAR PARTICLE TRACKS (NO RETARDATION)

000079

FIGURE 4-12. CAPTURE ZONE, 10-YEAR SCENARIO, NO RETARDATION



STATE PLANAR COORDINATE SYSTEM 1927

17-JUN-1997

LEGEND:

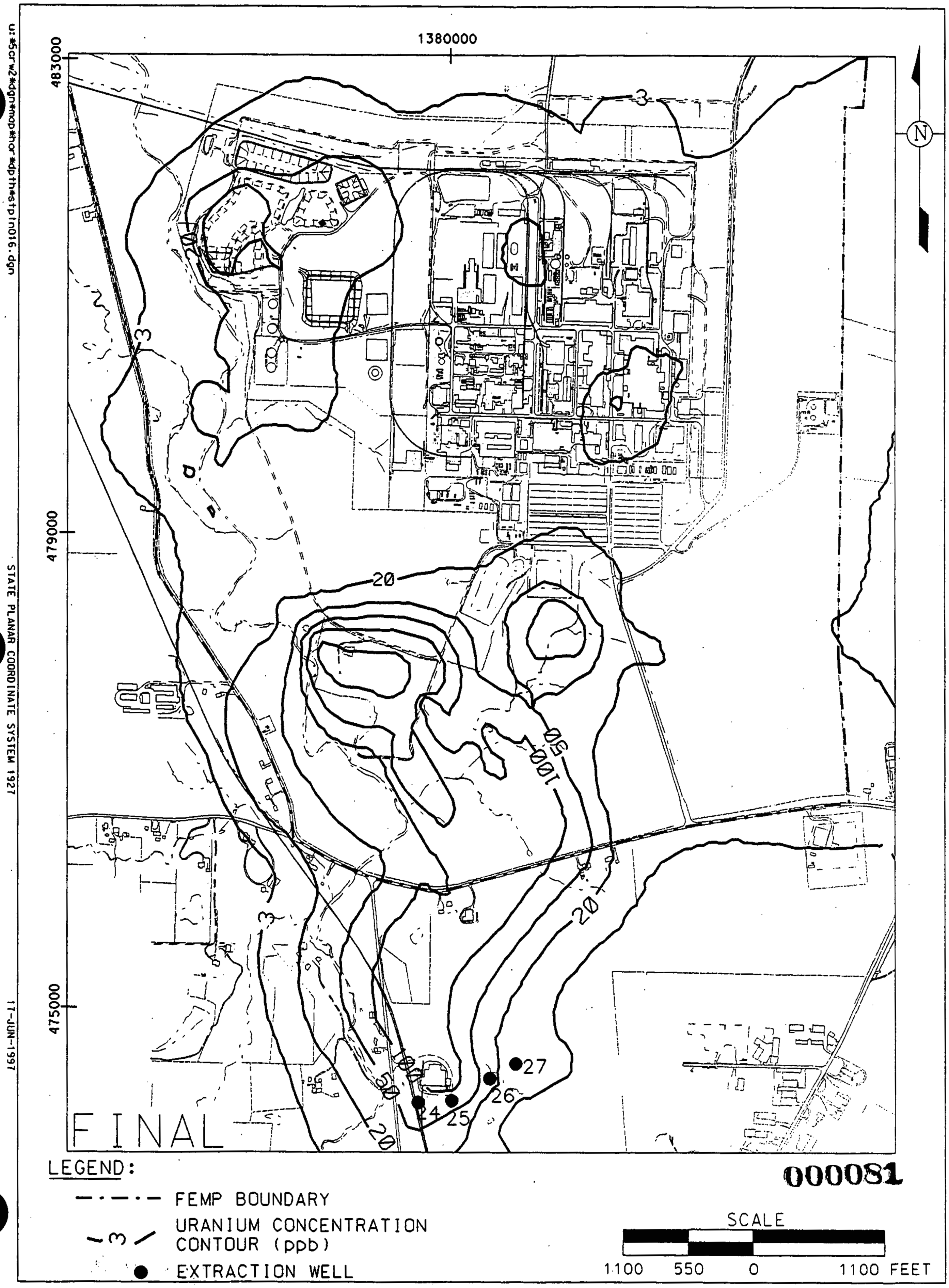
FEMP BOUNDARY

10-YEAR PARTICLE TRACKS (RETARDATION = 12)

EXTRACTION WELL

000080

FIGURE 4-13. CAPTURE ZONE, 10-YEAR SCENARIO, RETARDATION=12



000081

FIGURE 4-14. URANIUM CONCENTRATIONS AND PUMPING WELLS FOR 10-YEAR SCENARIO, YEAR 2

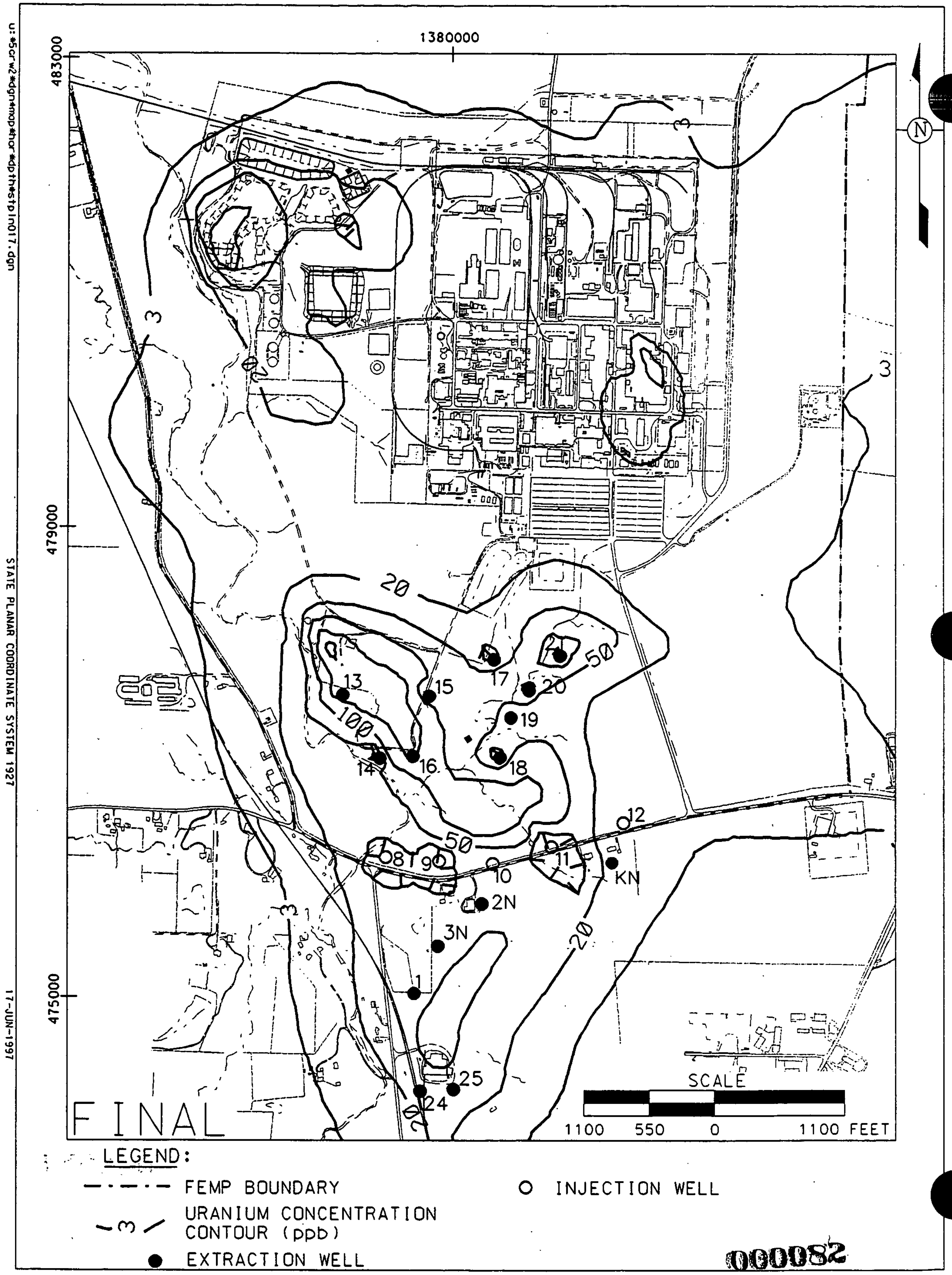


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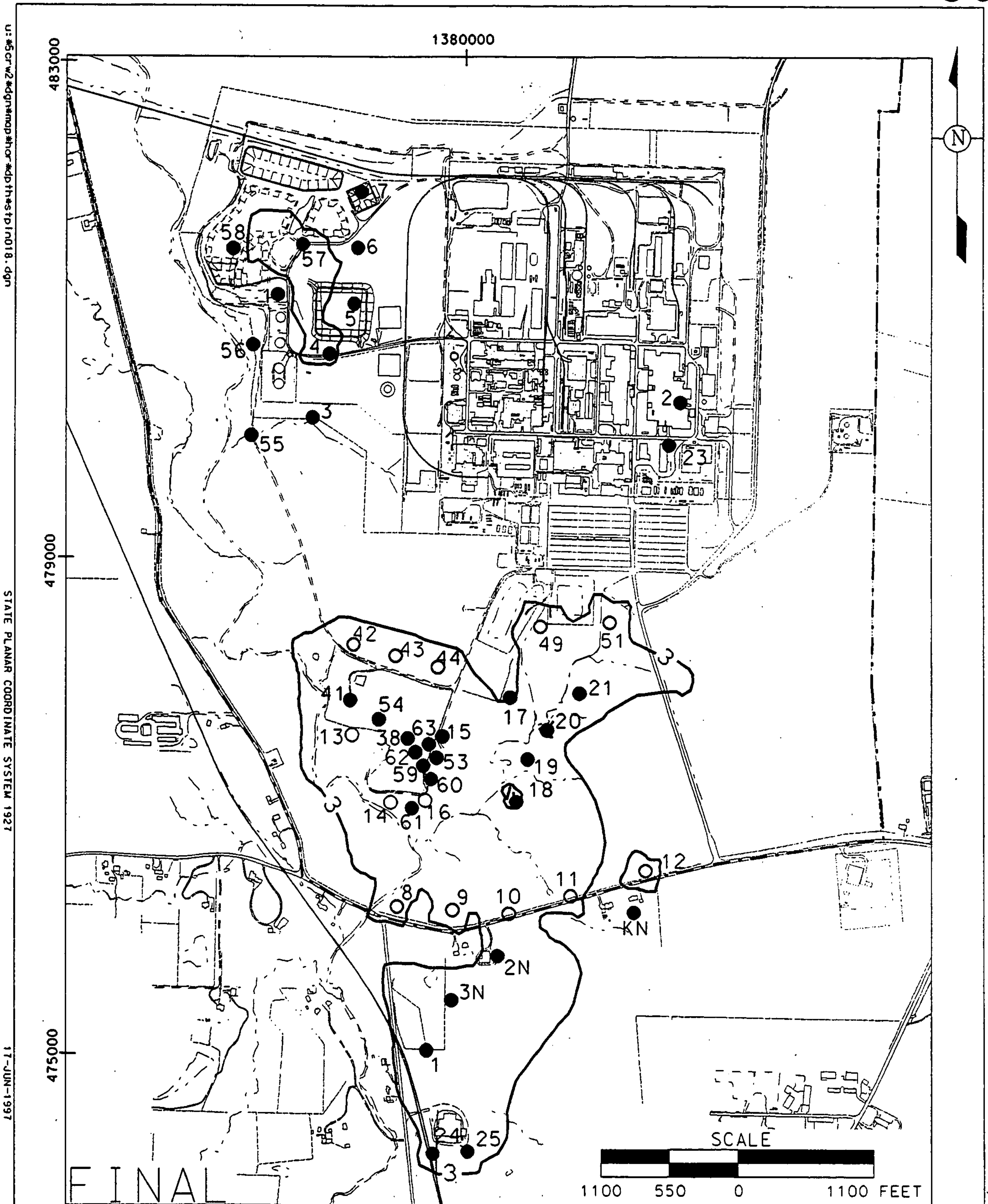
FIGURE 4-15. URANIUM CONCENTRATIONS AND PUMPING/INJECTION WELLS FOR 10-YEAR SCENARIO, YEAR 7

8 5 1



LEGEND:

FEMP BOUNDARY

URANIUM CONCENTRATION CONTOUR (ppb)

INJECTION WELL

EXTRACTION WELL

000083

FIGURE 4-16. URANIUM CONCENTRATIONS AND PUMPING/INJECTION WELLS FOR 10-YEAR SCENARIO, YEAR 10

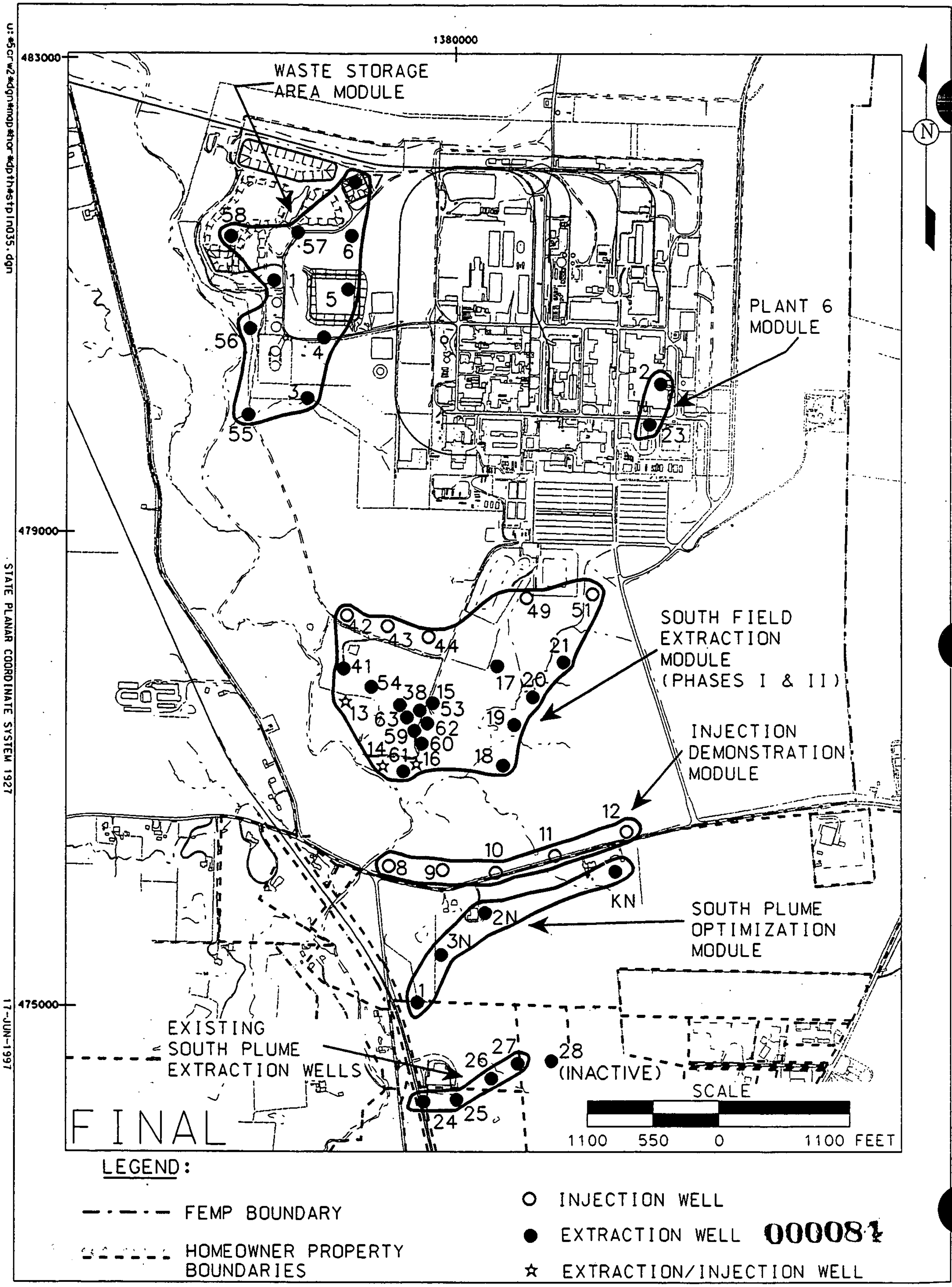


FIGURE 4-17. GROUNDWATER RESTORATION MODULES

The South Plume Optimization Module consisting of 4 proposed extraction wells will be installed off property south of the FEMP to restore the off-property portion of the uranium plume quickly and cost effectively. The location and final number of wells will be finalized upon completion of negotiations with the affected landowner.

The Injection Demonstration Module along the southern fenceline of the FEMP consists of five on property injection wells which will help to speed the off property clean up of the uranium plume and help to block further off property plume movement through the establishment of a hydraulic barrier. Treated groundwater will be re-injected into the aquifer at 200 gpm per well for a total injection rate of 1000 gpm in this module.

The South Field Module (Phase I) consists of 9 on property extraction wells which are currently installed but which will not begin pumping until associated piping is completed. After surface excavations in the South Field area are completed in 2003, an additional eight extraction wells and five up gradient injection wells (Phase II) are scheduled to be installed to speed the aquifer restoration in this area. The South Field Module (Phases I and II) will pump the majority of the groundwater to be extracted from the aquifer because this area has the highest uranium concentrations on site.

The Waste Storage Area Module consists of ten extraction wells which will become operational in 2004 after surface excavations are complete. These wells will pump contaminated groundwater from beneath what were the waste pits for the production operations at the FEMP.

Finally, the Plant 6 Area Module consists of two extraction wells which will become operational in 2004 after Plant 6 has been removed. These two wells will pump uranium contaminated groundwater from beneath this area.

4.4 SUMMARY OF OTHER IMPORTANT FINDINGS IN THE PRELIMINARY EVALUATIONS

Other important findings not specifically discussed in the previous sections are presented in this section. These findings will also be considered when finalizing the baseline remedial strategy.

4.4.1 Optimal Extraction Well Location

Mass removal efficiency of the groundwater extraction well can be greatly improved when installed in the hot spots instead of along the edge of groundwater plume. However, due to the soil remediation activities in the source areas, installation of extraction wells in the hot spots can not be initiated until completion of the soil remediation.

The total mass required to be recovered from the aquifer in order to achieve the concentration-based cleanup goal is lower when more extraction wells are located directly in the hot spots. Consequently, a shorter cleanup time, a less extracted groundwater volume, and less contaminant mass discharged to the Great Miami River can be achieved.

In order to maximize the recovery efficiency, certain off-property extraction wells may need to be located close to private houses or farming facilities. These preferred locations may not be obtainable because of landowner constraints, and secondary locations may be required.

4.4.2 Effects of Groundwater Injection

Groundwater injection along the southern property line can effectively stop further migration of the on-property portion of contaminant plume into the off-property area. The stagnation zone in the off-property area which exists in the FS strategy can be effectively eliminated by injection along the southern fence line. Groundwater injection can also permit higher groundwater extraction rates while not exceeding the net extraction rate limit of 4000 gpm. Therefore, the groundwater flushing rate through the contaminated zone can be increased.

Modeled plume expansions in both the horizonal and vertical directions due to groundwater injection are not significant. However, proper coordination between extraction and injection operations should be maintained to prevent any significant expansion during remediation. Additional deeper monitoring wells around the injection wells may also need to be installed.

4.4.3 Groundwater Treatment Decision

Under the groundwater treatment decision hierarchy described in Section 3.1.4, the combined flow from the existing South Plume Recovery Well System will usually be the only untreated groundwater that has uranium concentrations above 20 ppb. Because the remaining treatment capacity can not treat the entire South Plume flow and it was assumed in the evaluation that the combined South Plume flow cannot be divided further for partial treatment, the baseline 2000 gpm treatment capacity cannot always be fully utilized in the scenarios, as indicated in Tables 4-2, 4-4, 4-6, and 4-8. Although the discharge limits are achieved in the evaluations, in order to further reduce mass loading to the Great Miami River (as a good management practice), it may be desirable during remedial design to examine methods to permit the splitting of the South Plume flow for partial treatment so that the available treatment capacity can always be utilized.

Section 5.0

5.0 FINALIZATION OF THE BASELINE STRATEGY

As presented in Section 4.0, the preliminary baseline strategy was developed based on assumptions of unconstrained funding and unrestricted off-property access. These assumptions were made to simplify the overall cost-benefit evaluation process. However, before the engineering design can be initiated, the actual funding profiles and current off-property access constraints need to be considered. Also, in order to provide representative comparisons with the FS base case remedy, the "maximum" plume configuration employed in the FS Report (representing the maximum reported plume concentrations throughout the FEMP's historical period of record) was used to conduct all of the modeling simulations for the preliminary evaluations and ultimately to identify the preferred scenario. For detailed design purposes, the most recent "current condition" plume configuration (based on actual recent monitoring data) should be used so that well locations are situated as accurately as possible.

A uranium profile sampling task using the Geoprobe™ technique was conducted between October 1996 and March 1997 to collect more data to supplement the existing data for updating the uranium plume delineation. The relatively unobtrusive nature of the Geoprobe™ technique permitted the FEMP to obtain key off-property groundwater contamination profile data from beneath a series of active agricultural fields. The Geoprobe™ data was used to supplement data from the permanently installed Type 2 and Type 3 monitoring wells located at the boundaries of the agricultural fields. The Geoprobe™ was also used to provide additional resolution of the vertical dimensions of the plume in the vicinity of the Injection Demonstration wells. Appendix G summarizes the Geoprobe™ results and the portrayal of a revised current-condition plume configuration.

This section presents the process of finalizing the preliminary baseline strategy by considering these three major implementation issues (funding profiles, off-property access constraints, and current condition plume configuration). The finalized baseline remedial strategy developed in this section will then be the basis for the remedial design.

5.1 SUMMARY OF THE IMPLEMENTATION ISSUES

5.1.1 Current Uranium Plume

The initial uranium plume in all the model simulations conducted during the preliminary evaluation process was based on the maximum concentrations measured in the FEMP's monitoring wells prior to 1994. The development procedures for this plume were presented in Appendix F.7 of the Operable Unit 5 FS. This synthetic "maximum" plume is a very conservative representation of the actual uranium plume in terms of size and concentration levels. It was used in the FS to ensure that the selected groundwater remediation system will maintain a sufficiently large hydraulic capture zone and that the broad response actions evaluated in the FS (no action, containment, and active restoration) were compared fairly. However, use of this plume during the detailed design process could inadvertently lead to the selection of extraction well locations outside of the actual plume and result in lower mass recovery efficiency. Therefore, it is necessary to consider a more realistic plume delineation based on the most recent data when finalizing the remedial system design. The realistic plume may be used to fine tune the well locations and projections of the system performance measures.

Groundwater data collected through the South Plume Design, Monitoring, and Evaluation Program Plan (DMEPP) in the past three years, the South Field Phase I extraction well borings, and the recently completed uranium profile data using the Geoprobe™ sampling technique provide a more up to date delineation of the uranium plume. More details of the Geoprobe™ uranium profile sampling task, result interpretation, and the development process of the updated uranium plume delineation using a 3-D kriging technique are summarized in Appendix G.

Significant differences between the synthetic "maximum" plume and the currently measured off-property plume can be seen in Figure 5-1. These differences can be attributed to operation of the South Plume Recovery Well System in the last 3 years as well as reduction of contaminated surface runoff discharged into Paddys Run. The updated plume shown in Figure 5-1 was used as the new initial condition in model simulations to finalize the off-property well locations and performance projections of the baseline remedial strategy. When the updated plume was used in model simulations, the time zero in the model was set at the beginning of FY97.

Other interim interpretations of the uranium plume using partial Geoprobe™ sampling results were also used in additional modeling simulations conducted to provide important information necessary for selecting the final baseline remedial strategy to be discussed in this section. Details of these supporting modeling simulations which were performed during the same period of time when the Geoprobe™ sampling task was conducted, are presented in Appendix E. In general, selection of the u:#5crw2#dgn#map#nor#dpth#brsr039.dgn

STATE PLANAR COORDINATE SYSTEM 1927

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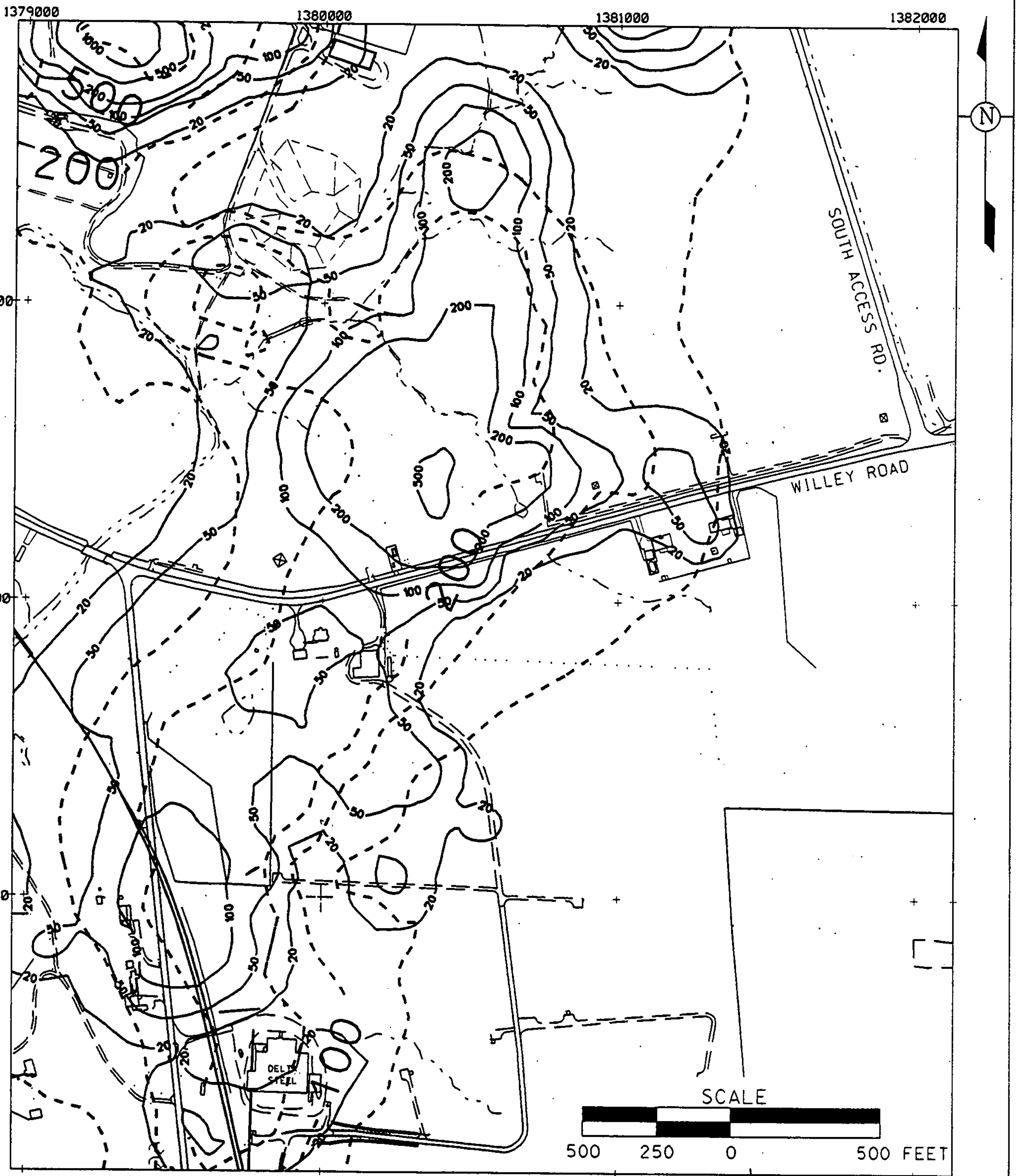

LEGEND:

KRIGED PLUME - MODEL LAYER 2 (APRIL, 1997)

SYNTHETIC MAXIMUM PLUME

FEMP BOUNDARY

FINAL

000090

FIGURE 5-1. COMPARISON BETWEEN THE MAXIMUM AND CURRENT URANIUM PLUMES number and location of South Plume optimization wells, containment of the on-property plume, groundwater injection depth, compliance with the FEMP outfall limits, and implementation schedules of system modules were the major issues evaluated in these additional modeling simulations before the baseline remedial strategy was finalized.

5.1.2 Off-Property Access Considerations

The preliminary baseline remedial strategy selected at the conclusion of Section 4.0 contains four new proposed off-property extraction wells to enhance the overall restoration of the off-property plume. These four new wells are identified as Wells 1, 3N, 2N, and KN on Figure 4-17.

All four of the wells are situated on private property owned by Knollman Farms, Inc. The locations of the four wells were identified through modeling simulations and are designed to accommodate the desire of EPA, OEPA and DOE to shorten overall off-property remediation time, improve mass removal efficiency, and minimize the further expansion of the off-property plume. With these four new extraction wells in place, only the western two existing South Plume recovery wells (shown as Wells 24 and 25 on Figure 4-17) are necessary for maintaining full hydraulic capture of the off-property plume. The locations for the four wells shown on Figure 4-17 are idealized locations used to perform the preliminary modeling simulations. They do not necessarily consider property owner access considerations and localized land use constraints. It was recognized in the development of the modeling simulations that final locations would need to be adjusted as appropriate to accommodate actual property owner constraints and desires, once successfully negotiated as part of the ongoing remedial design process.

Several meetings were held between DOE, EPA, OEPA, and the property owner before October, 1996 to discuss property access issues of concern to the property owner. As part of the discussions, the nature of the benefits to be provided by the four new wells, in terms of off-property aquifer restoration time and further plume expansion, were reviewed. It was acknowledged during the discussions that two of the new wells (1 and 3N), which are to be placed along the main axis of the off-property plume, are key to shortening off-property cleanup time because they address the area where the highest off-property groundwater concentrations are exhibited (this area was shown by the modeling simulations to be the off-property rate-limiting area). The remaining two wells (2N and KN) function primarily to halt the further expansion of the plume and to increase overall mass removal efficiency from that achievable by using the existing South Plume recovery wells alone. These two wells do not, however, contribute meaningfully to the shortening of the overall off-property cleanup time since, by function, they do not reside in the rate-limiting area where contaminant concentrations are highest. It was also acknowledged that in the absence of Wells 2N and KN, the plume would continue to expand but within the geographic confines of the hydraulic capture zone created by the western four South Plume recovery wells.

The property owner has expressed specific concerns to DOE, EPA, and OEPA with any new pipelines which need to cross the farm field and Wells 2N and KN, indicating that the initial installation of these new components as well as the long-term activities associated with the operation of these two wells may cause unacceptable levels of disruption and disturbance (considering the proximity of the potential pipelines and wells to the landowner's residential dwellings and cattle breeding operations). The property owner is more agreeable to the installation of Wells 1 and 3N, considering their role in addressing the core of the off-property groundwater plume and their proposed location along the edge of a farm field away from dwellings and barns.

DOE conducted additional modeling simulations between December 1996 and March 1997 to evaluate the technical merits of each of the four potential South Plume optimization wells and the associated piping network in light of the landowner's concerns and the updated uranium plume delineation. A series of thirty one (31) new modeling simulations were conducted to further evaluate the performance of the wells, the merits of moving the wells to alternate on- and off-property locations, and to address other important design and operational issues. The results of these simulations are summarized in Section 5.2.1, and the details are provided in Appendix E.

In March 1997 the property owner reemphasized specific concerns regarding any new wells and pipelines inside the farm field and/or close to residential dwellings after the additional field sampling and modeling simulations were completed and presented to the owner. It needs to be recognized that without the property owner's concurrence, it will require a lengthy condemnation process in order to obtain access for any new off-property wells and associated pipelines. Currently, DOE does not plan to proceed with the condemnation process if these wells are not critical to the completion of aquifer restoration.

5.1.3 Funding Constraints for Fiscal Years 1997 and 1998

In order to implement the preliminary baseline remedial strategy, it will require close to 10 million dollars from the FEMP's FY97 budget to complete the South Field Extraction Phase I System (remaining piping network), the South Plume Optimization Module (four new wells and piping network), the AWWT Facility Expansion, and the fenceline Groundwater Injection Demonstration Module (which is funded separately through a DOE Headquarters technology demonstration grant). However, under the current funding schedule, the annual funding available for these projects in FY97 and FY98 will be about 3 and 7 million dollars, respectively. Therefore, the components assumed to be completed in FY97 under the unconstrained preliminary baseline strategy case will need to be constructed sequentially over the years FY97 and FY98. Currently, there is no foreseen out-year funding problem for installing the remaining modules of the system -- South Field Phase II, Waste Storage Area, and the Plant 6 Area modules -- in accordance with the desired schedule defined in the preliminary baseline strategy.

Among all the system performance measures of the Aquifer Restoration and Wastewater Treatment Projects, compliance with the outfall criteria will be given the highest priority during remediation. Sufficient wastewater treatment capacity is critical for maintaining the outfall compliance when all the FEMP remediation projects are in operation, and for producing needed water for the Injection Demonstration Module. Therefore, the AWWT Facility Expansion is selected as the lead project to be funded in FY97. Following construction, the expanded groundwater treatment capacity will be available by April 1998 as assumed in the unconstrained funding case.

The other two components assumed in the preliminary strategy to be initiated in FY97 under the unconstrained funding case (South Plume Optimization Module and South Field Phase I System) will be delayed until FY98 and, following construction, brought on line in FY99. Potential impacts of various implementation schedules were evaluated by simulating twelve start-up schedule evaluation scenarios as defined in Section E.4.2.1 in Appendix E.

5.2 MODIFICATIONS TO THE PRELIMINARY BASELINE STRATEGY

The necessary modifications to the preliminary baseline strategy identified in Section 4.0 to accommodate the off-property access considerations, the current uranium plume, and funding constraints for FY97 and FY98 are identified in this subsection.

The preliminary baseline strategies described in Section 4.0 include four new off-property wells (i.e., 1, 3N, 2N, and KN). These four (4) off-property wells were located on land owned by the same land owner. Locations of these wells are based on the synthetic "maximum" plume developed in the Operable Unit 5 FS (DOE 1995), which is a combination of all the well-specific maximum detected uranium concentrations before the end of 1993. Appendix E summarizes additional model simulations conducted to further evaluate the need for and the optimal location of each of these wells based on the current uranium plume. Potential impacts to the outfall conditions under different total extraction rates of the South Plume Optimization Module were also estimated.

The preliminary baseline strategies also include five groundwater injection wells along the FEMP's southern fenceline. These groundwater injection wells were designed to minimize further cross-fenceline migration of the on-property uranium plume and to increase the contaminant flushing rate in the off-property area. However, groundwater injection may push the uranium plume, in the vicinity of the injection wells, deeper into the aquifer. Potential impacts of various groundwater injection depths on the vertical expansion of the uranium plume were further evaluated by conducting cross-sectional particle tracking simulations. The main purpose of these simulations was to provide necessary information for determining proper injection well screen intervals and potential need of additional on-property extraction wells so that further vertical expansion of the uranium plume can be minimized during the planned groundwater injection operation.

5.2.1 Path Forward for the South Plume Optimization Module

Appendix E contains the results of the thirty one (31) modeling simulations conducted to support the deliberations regarding the off-property landowner's concerns with locations of potential optimization wells and other important design and operational issues of the South Plume Optimization Module. The results of the simulations, presented in detail on the maps and tables provided in Appendix E, reveal the following principal conclusions regarding the South Plume Optimization Module:

- All of the scenarios result in approximately the same degree of off-property plume expansion, as indicated by the predicted future position of the 20 ppb total uranium FRL concentration contour.

- In all cases, the area of expansion resides within the capture zone of the South Plume recovery wells (provided South Plume recovery wells 24, 25, 26, and 27 shown on Figure 4-17 remain in operation).

- Mass removal efficiency of Well KN is significantly lower than the other potential optimization wells.

- Off-property cleanup times for all scenarios are nearly identical.

- Scenarios with delayed or no groundwater injection are not nearly as effective in restoring the off-property portion of the plume (as evidenced by larger residual plume at the end of FY03). The expansion of the plume is about the same as the other scenarios, however the regional drawdown impacts are much more pronounced.

- The outfall concentration limit may be exceeded when the South Plume Optimization Module is operated at the full extraction capacity, specially when the optimization wells are directly tied in to the South Plume forced main.

Other important findings discussed in Appendix E include the optimal range for injection well screen interval and the need of an on-property extraction well upgradient of the fenceline injection wells in order to reduce further downward expansion and cross-fenceline migration of the uranium plume. These summary results were shared in detail with the landowner, EPA, and OEPA at a series of meetings held between September 1996 and March 1997. Most of the maps that were presented at the meetings are also provided in Appendix E.

5.2.1.1 Summary of the Design Modifications

Based on results of all the additional modeling simulations and subsequent evaluations, a path forward for the South Plume Optimization Module was agreed on by DOE, EPA, and OEPA. The property owner's specific concerns have also been fully considered and incorporated into this path forward. Figure 5-2 shows all the wells to be included in the final baseline remedial strategy. RW-6 and RW-7 are the two optimization wells to be installed and operated for the initial South Plume Optimization Module. These two wells will be located along the south edge of the impacted property and will be tied in to the existing South Plume Removal Action pipeline using pipelines which will also be installed along the landowner's property line.

In general, modifications to the preliminary South Plume Optimization Module design include the elimination of proposed Well KN from further consideration; the addition of Well 2N at a new location agreeable to the landowner; and the placement of Well 3N into a "contingency" mode for future consideration based on actual remedy performance data. Based on the preferences of the landowner, it was agreed that the two South Plume Optimization Module wells (Wells 1 and 2N) would be routed to the existing South Plume discharge line and combined with the flow from the

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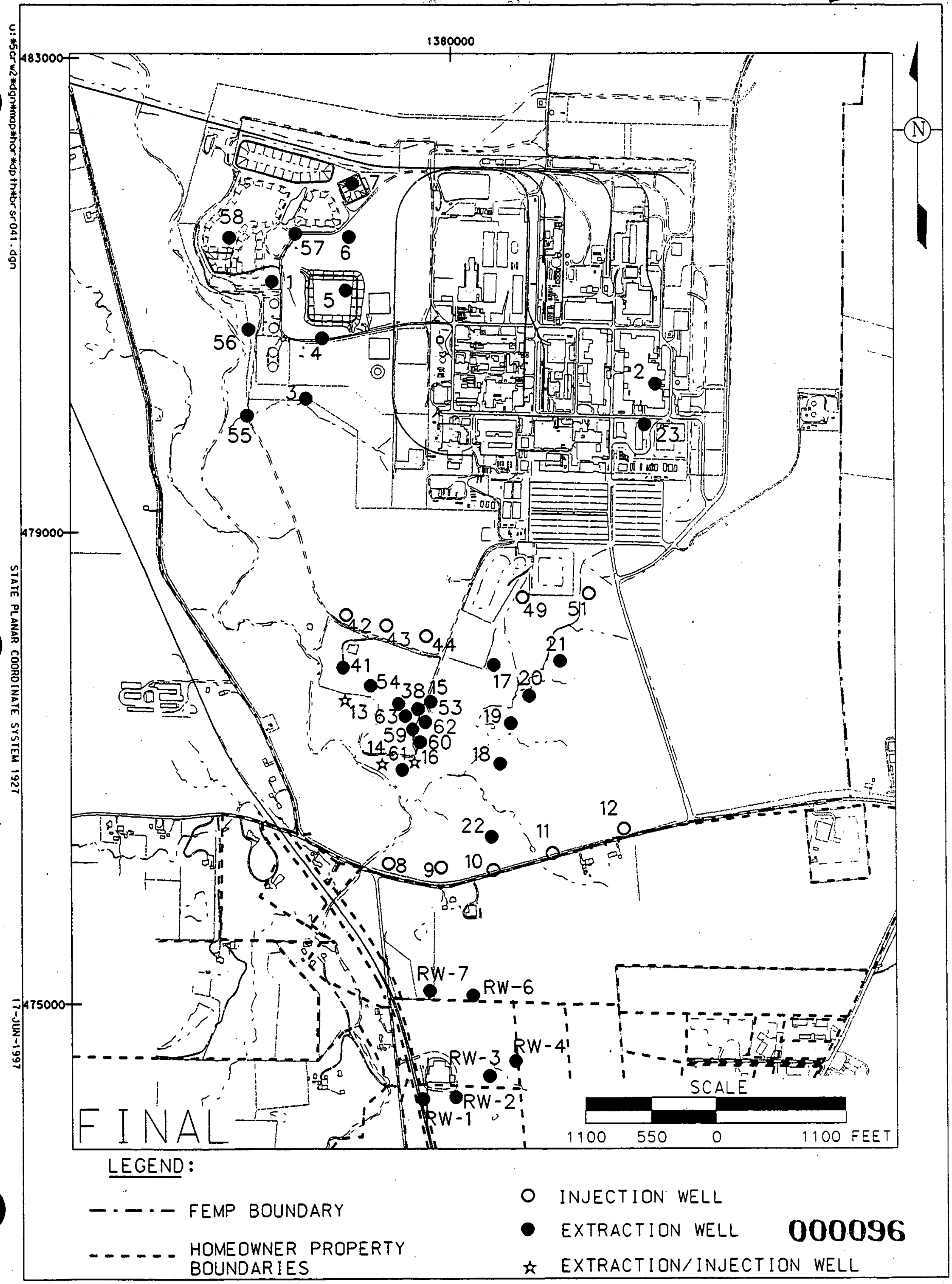

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FIGURE 5-2. WELL LOCATIONS FOR THE BASELINE GROUNDWATER REMEDIAL STRATEGY

South Plume Removal Action wells. The two new wells will also be installed as low-profile "flush mount" wells as described in the South Plume Optimization Module prefinal design package. For clarity, these two new wells will be renamed as South Plume Recovery Wells "RW-6" and "RW-7" for use in followup future design submittals.

RW-1, RW-2, RW-3, and RW-4 in Figure 5-2 are the four existing South Plume recovery wells. Extraction Well 22 is added to the South Field Phase I System and will be designed to use double headers like other on-property extraction wells. The well-specific optimal injection screen lengths and elevations will be selected within a general 50-foot interval (i.e., 510 feet amsl to 460 feet amsl). Extraction/injection rate schedules of all the wells included in the baseline remedial strategy are presented in Section 5.2.3.

5.2.1.2 Path Forward to Incorporate Design Modifications

The FEMP proceeded with remedial design activities for the South Plume Optimization Module assuming Wells 1 and 3N would be installed. This was necessary to meet the enforceable remedial design schedules and document delivery dates contained in the Operable Unit 5 RD Work Plan. The preliminary and prefinal design packages for the South Plume Optimization Module therefore included Wells 1 and 3N along with the accompanying piping and infrastructure.

To meet the October 1, 1996 document submittal date for the South Plume Optimization Module preliminary design package, it was assumed that Wells 1 and 3N will follow a new northward right-of-way access back to the FEMP property where on-property tie ins to the South Field treatment and bypass headers can be accommodated. The landowner, however, did not agree to this right-of-way access. Alternately, it was proposed that Wells 1 and 3N will be tied in to the existing South Plume Removal Action pipeline following an existing eastward right-of-way previously negotiated with the landowner. This alternate piping design was included in the prefinal design package which was submitted to EPA on January 15, 1997. The final design package of the South Plume Optimization Module will incorporate the agreed upon modifications described in Section 5.2.1.1 (i.e., RW-6 and RW-7 as shown in Figure 5-2 which will be tied in to the existing South Plume Removal Action pipeline following the existing eastward right-of-way).

If the ongoing technical and logistical deliberations during the remediation regarding performance of the initial system result in the third optimization well being required in the future, then an additional add-on restoration module ("South Plume Optimization II") will be included in the FEMP's restoration program to accommodate this outcome of the deliberations. Design of this module would then be conducted under a new schedule and task description (to be developed for EPA approval following the conclusion of the deliberations) and which will be included as a formal addendum to the RD Work Plan.

The technically-based contingency triggers that may result in the need to install Well 3N (to be renamed as "RW-8") at a later date are discussed in Section 5.4.6. Activation of the contingency well, should it be necessary, may result in the need to gain new landowner access at that time, pending on the potential well location selected. The contingency well may also result in the need for a second discharge line (i.e., separate from the South Plume discharge line) to permit the segregation of higher concentration flows for subsequent preferential treatment. The need for the second discharge line would be evaluated based on actual remedy performance data assembled at that time, coupled with the consideration of landowner access preferences and constraints.

5.2.1.3 Regulatory Considerations Associated With Off-Property Plume Expansion

As discussed in the previous section, the FEMP is proceeding with detailed remedial design with two initial optimization wells (i.e., Well RW-6 and RW-7 as shown in Figure 5-2) and the flexibility for a third well in the future, if necessary. The initial two-well optimization module and the existing South Plume Recovery Well System will be utilized until the deliberations concerning system performance result in a definitive path forward regarding the need, potential location, and feasibility for the third well as part of the restoration program. This section reviews the regulatory considerations associated with expansion of the leading edge of the plume (within the confines of capture zone created by the South Plume recovery wells) if optimization wells along the eastern edge of the off-property plume are not installed (as shown in Figure E-27 of Appendix E).

Regulatory acceptance of this controlled expansion can be supported by the following points:

- The affected property owner has not granted approval for placing new wells on his property except along the property line and edge of the farm field and there are no feasible alternate locations for additional wells to stop the expansion of the plume

- The plume will be contained in the overall hydraulic capture zone created by other extraction wells
- The off-property cleanup time will not be extended as a result of the action
- The uranium concentrations in the expansion area are projected to remain relatively low over the duration of the action (greater than 20 ppb, but less than 50 ppb)
- The impacted area currently has an alternate water supply available through the new public water supply
- Groundwater will not be used for irrigation or other purposes during remediation
- Groundwater conditions in the impacted area will be closely monitored as part of the Integrated Environmental Monitoring Plan (DOE 1996c).

The above listed reasons provide sufficient justification under the guidance contained in EPA's OSWER Directive No. 9283.1-2 for approval of a limited or no action response for all or part of a contaminated groundwater zone at a CERCLA site (EPA 1998). It needs to be recognized that the modified baseline strategy does provide a limited response for this affected portion of the plume, as it is expected to attenuate within the capture zone created by the other off-property wells, and is therefore under the hydraulic control of the overall system.

RCRA regulations provide similar approval authorities for controlled attenuation of off-property groundwater zones at 40 CFR part 264.525 which states that "If the owner/operator is unable to obtain the necessary permission to undertake corrective action beyond the facility boundary, and can demonstrate to the satisfaction of the Regional Administrator that despite the owner/operator's best efforts, he/she is as a result unable to achieve media cleanup standards or levels beyond the facility boundary, then media cleanup standards or levels must be achieved to the extent practicable, as specified by the Regional Administrator."

5.2.2 Funding-Based Implementation Schedule

The implementation schedule for the Groundwater Injection Demonstration, South Field Phase I System, and the South Plume Optimization Module(s) will need to be coordinated with the funding schedule. The AWWT Expansion will be completed in early 1998 as originally scheduled. Because the treated groundwater is needed for injection, the Groundwater Injection Demonstration along the southern fence line will be initiated at the same time when the AWWT Expansion is completed. The necessary piping network for the injection operation is expected to be completed with the technology demonstration grant funding in FY97. The complete South Field Phase I System and the initial South Plume Optimization Module (RW-6 and RW-7) will be brought on line by early 1999. Extraction Well 22 will be designed and constructed as part of the South Field Phase I System. It is expected that both the Groundwater Injection Demonstration Module and extraction Well 22 will start operation by fall of 1998. Implementation schedules for the South Field Extraction System Module Phase II, Waste Storage Area Module, and Plant 6 Module remain the same as in the preliminary baseline strategy (i.e., by FY04).

5.2.3 Extraction/Injection Rate Schedule

Table 5-1 summarizes the modified extraction/injection rate schedule for the baseline groundwater remedial strategy. Differences in the rate schedules between the preliminary and finalized baseline strategies (see Tables 4-5 and 5-1) include necessary modifications due to modifications in the South Plume Optimization Module and the funding-based implementation schedule. Due to the low off-property residual concentrations, all the off-property wells and the Southern Fence Line Injection System (i.e., extension of the Groundwater Injection Demonstration Module) are also turned off at the end of FY03 in the modified rate schedule.

5.3 PERFORMANCE PROJECTIONS

The projected performance indicators for the finalized baseline strategy are summarized in this subsection.

5.3.1 Basic Performance Measures

After incorporating the necessary modifications described in Section 5.2, performance measures of the baseline remedial strategy are projected by model simulation using the updated uranium plume in the off-property area. As mentioned earlier, the first model year corresponds to FY97 in this simulation.

TABLE 5-1

EXTRACTION/INJECTION RATE SCHEDULE FOR THE BASELINE GROUNDWATER REMEDIAL STRATEGY

			Pumping Rates (gpm) (+) = Pumping (-) = Injecting			
System ID	Location	Well ID	1997	1998	1999-2003	2004-2005
I	Waste Pits	1	0	0	0	100
I	Waste Pits	3	0	0	0	100
I	Waste Pits	4	0	0	0	100
I	Waste Pits	5	0	0	0	100
I	Waste Pits	6	0	0	0	100
I	Waste Pits	7	0	0	0	100
I	Waste Pits	55	0	0	0	100
I	Waste Pits	56	0	0	0	100
I	Waste Pits	57	0	0	0	100
I	Waste Pits	58	0	0	0	100
	System Totals	Pumped	0	0	0	1000
		Injected	0	0	0	0
III	Plant 6	2	0	0	0	250
III	Plant 6	23	0	0	0	250
	System Totals	Pumped	0	0	0	500
		Injected	0	0	0	0
II	Fence Line Injectors	8	0	-200	-200	0
II	Fence Line Injectors	9	0	-200	-200	0
II	Fence Line Injectors	10	0	-200	-200	0
II	Fence Line Injectors	11	0	-200	-200	0
II	Fence Line Injectors	12	0	-200	-200	0
	System Totals	Pumped	0	0	0	0
		Injected	0	-1000	-1000	0
II	South Field Phase I	13	0	0	200	-200
II	South Field Phase I	14	0	0	200	-200
II	South Field Phase I	15	0	0	200	100
II	South Field Phase I	16	0	0	200	-200
II	South Field Phase I	17	0	0	100	100
II	South Field Phase I	18	0	0	100	0
II	South Field Phase I	19	0	0	100	200
II	South Field Phase I	20	0	0	100	200
II	South Field Phase I	21	0	0	100	0
II	South Field Phase I	22	0	200	200	200
	System Totals	Pumped	0	200	1500	800
		Injected	0	0	0	-600
II	South Field Phase II	38	0	0	0	300
II	South Field Phase II	41	0	0	0	400
II	South Field Phase II	53	0	0	0	300
II	South Field Phase II	54	0	0	0	400
II	South Field Phase II	59	0	0	0	300
II	South Field Phase II	60	0	0	0	300
II	South Field Phase II	61	0	0	0	200
II	South Field Phase II	62	0	0	0	200
II	South Field Phase II	63	0	0	0	300
	System Totals	Pumped	0	0	0	2700
		Injected	0	0	0	0

000101

TABLE 5-1
(Continued)

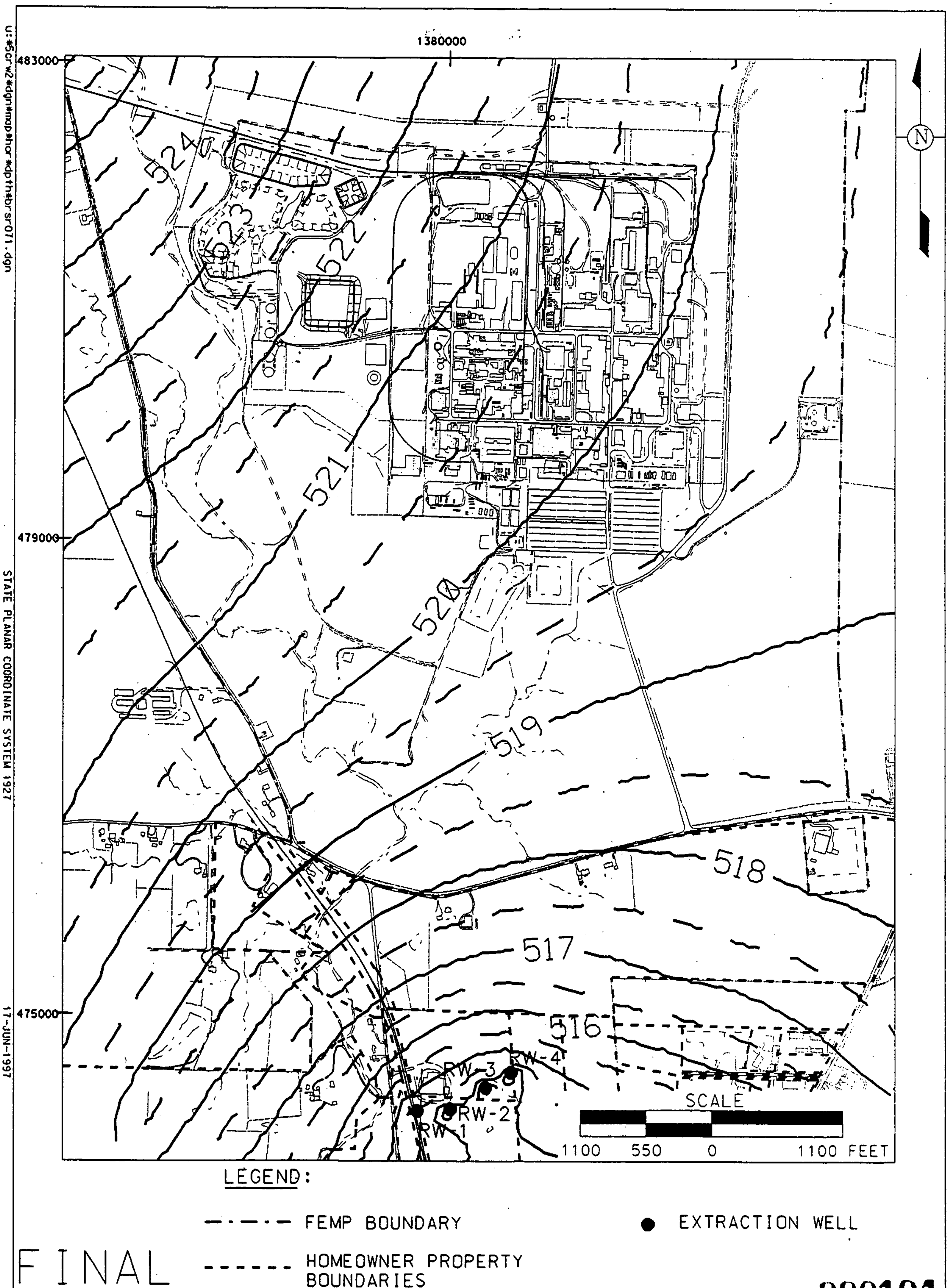
System ID	Location	Well ID	Pumping Rates (gpm) (+) = Pumping (-) = Injecting 1997	1998	1999-2003	2004-2005
II	North line of injectors	42	0	0	0	-200
II	North line of injectors	43	0	0	0	-200
II	North line of injectors	44	0	0	0	-200
II	North line of injectors	49	0	0	0	-200
II	North line of injectors	51	0	0	0	-200
	System Totals	Pumped	0	0	0	0
		Injected	0	0	0	-1000
IV	South Plume	RW-1	300	300	300	0
IV	South Plume	RW-2	300	300	300	0
IV	South Plume	RW-3	400	400	400	0
IV	South Plume	RW-4	400	400	400	0
IV	South Plume Optimization	RW-6	0	250	250	0
IV	South Plume Optimization	RW-7	0	250	250	0
	System Totals	Pumped	1400	1900	1900	0
		Injected	0	0	0	0
	Total Pumping		1400	2100	3400	5000
	Total Injecting		0	-1000	-1000	-1600
	Net Aquifer Extraction		1400	1100	2400	3400

Table 5-2 summarizes the important performance measures. Differences between performance measures of the preliminary and finalized baseline strategies (see Tables 4-6 and 5-2) are due to elimination and relocation of South Plume optimization wells, addition of the extraction Well 22, modified injection and extraction well depths, modified implementation schedule, and the updated off-property plume. In general the aquifer is projected to be restored in about 10 years as in the preliminary baseline strategy. As shown in Table 5-2, groundwater treatment capacity will be almost fully utilized throughout the remediation period even between years 8 to 10. This is necessary because the groundwater will need to be treated for iron before it can be injected regardless of the uranium concentration. This constraint was not imposed during the preliminary evaluation.

As shown in Table 5-2, the model estimated outfall concentrations are below the 20 ppb limit. However, because the estimated combined South Plume flow concentration in FY97 is slightly lower than the currently measured concentrations in the South Plume force main (i.e., 13 ppb modeled vs. 18 to 20 ppb measured), the total extraction rate of the South Plume Optimization Module was kept at 500 gpm. It is expected that the initial actual outfall concentrations when the system becomes operational in FY99 will be in between the values listed in Table 5-2 and Table E-15 in Appendix E. The differences between these two sets of estimated outfall concentrations are due to the different initial uranium plumes used in the model. A kriged plume was used in the model simulation for Section 5.0, while a manually contoured and more conservative plume (see Figure E-26) was used to produce the results in Table E-15. The extraction rate of the South Plume Optimization Module could be gradually increased during the operation, if the actual outfall concentrations remain below the 20 ppb limit.

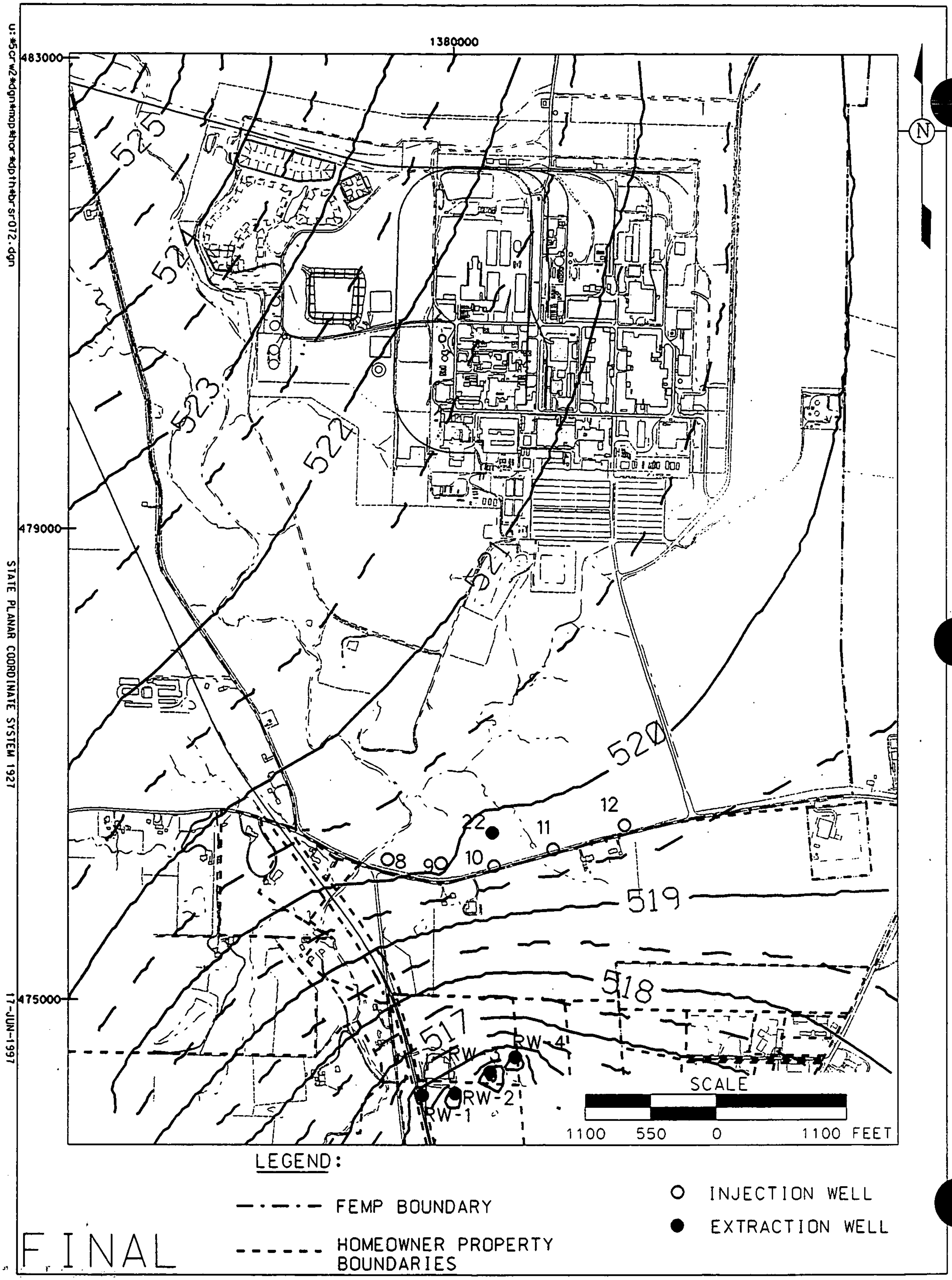
The estimated mass of uranium removed by specific modules under the baseline remedial strategy is shown in Table 5-3. Figures 5-3 through 5-6 show the modeled groundwater flow patterns under the finalized baseline groundwater remedial strategy. Corresponding groundwater drawdown contours are shown in Figures 5-7 through 5-10. The projected uranium concentration contours are shown in Figures 5-11 through 5-13.

In the absence of extraction wells along the eastern edge of the off-property uranium plume, the baseline strategy will, in effect, be relying on a controlled natural attenuation approach to address the expanding portion of the plume. The maximum extent of the off-property 20 ppb contour interval is



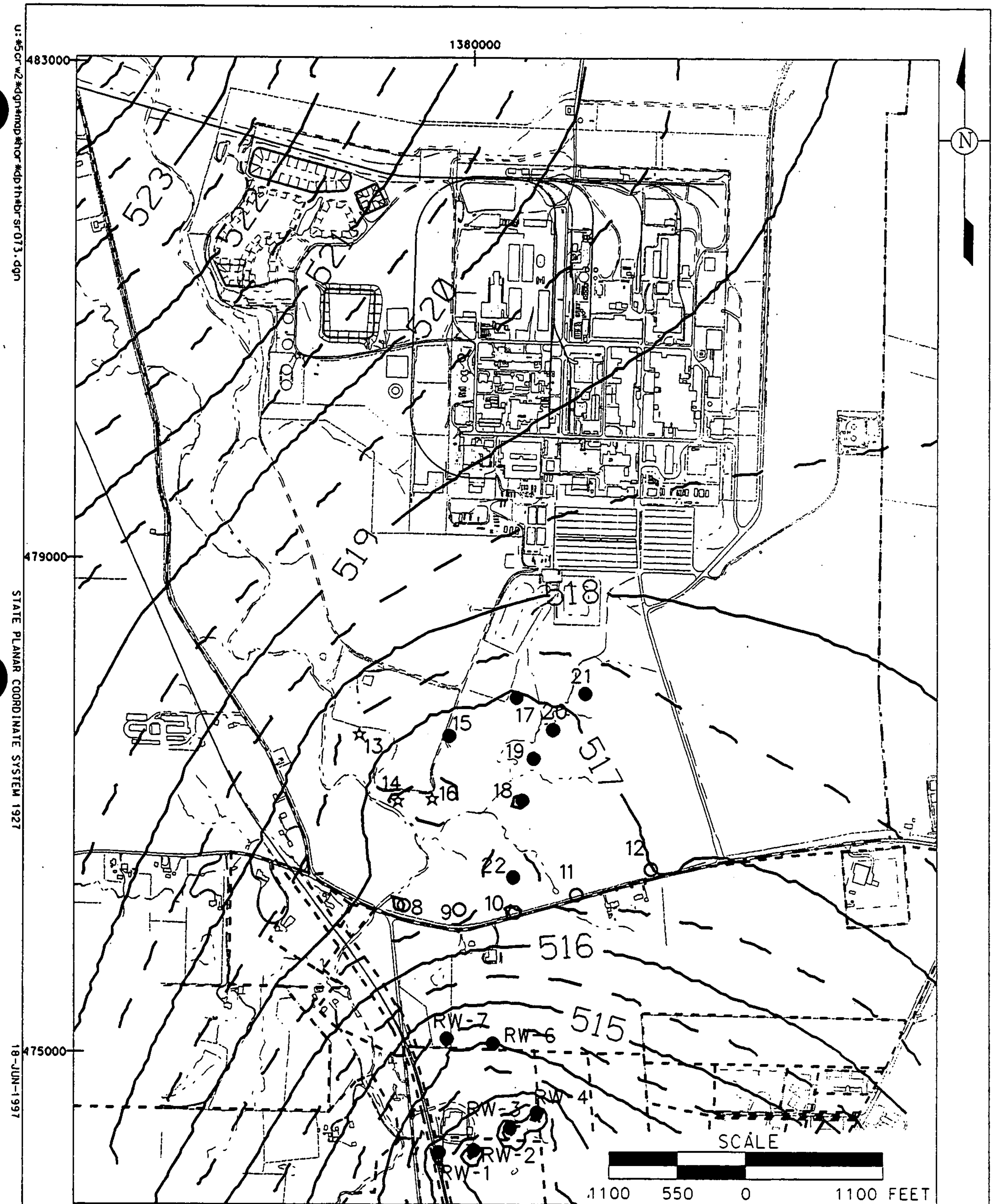
000104

FIGURE 5-3. MODELED GROUNDWATER ELEVATIONS FOR 1997



FINAL

FIGURE 5-4. MODELED GROUNDWATER ELEVATIONS FOR 19[illegible] 000105



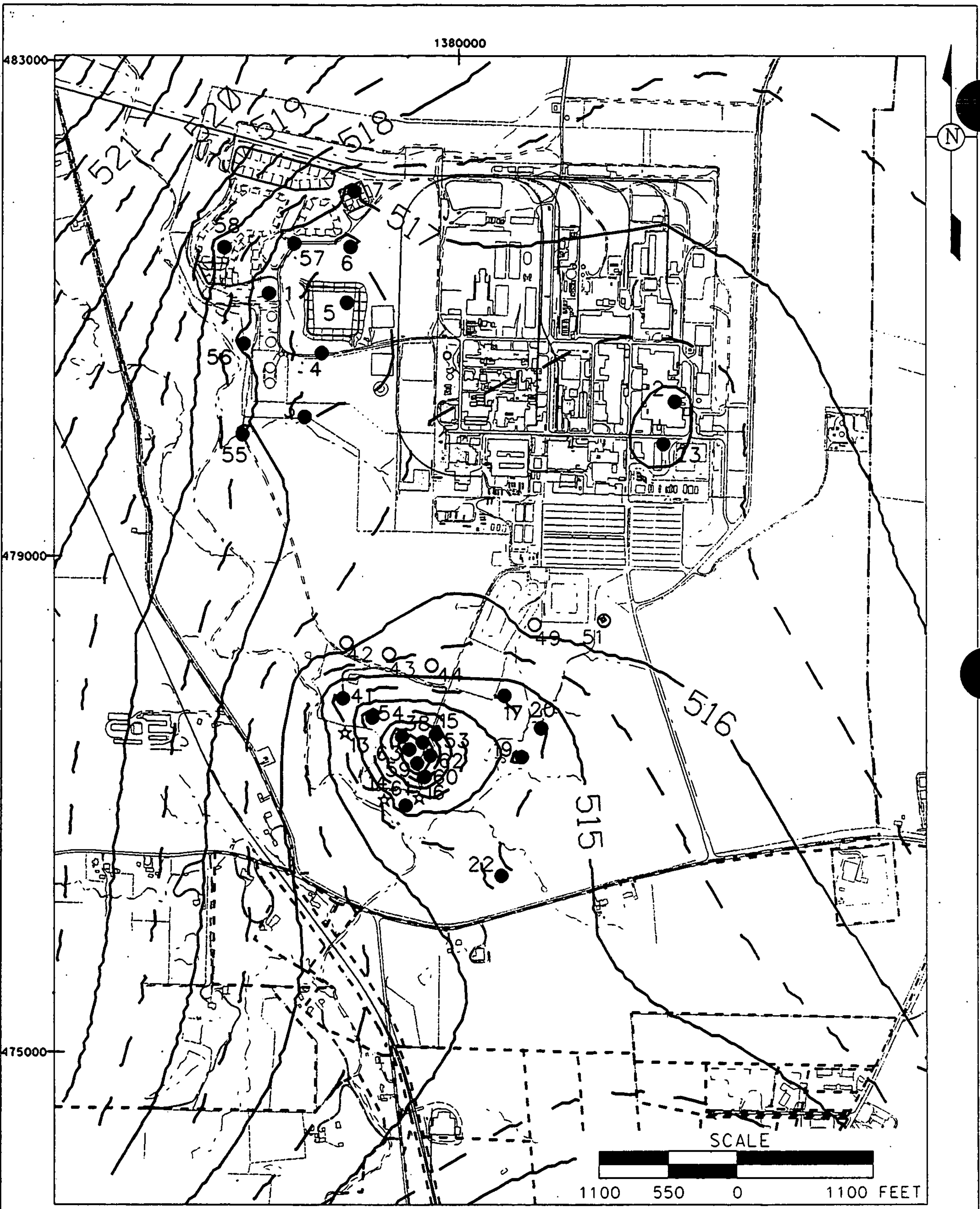
LEGEND:

- · — · — FEMP BOUNDARY
- - - - - - HOMEOWNER PROPERTY BOUNDARIES
- ○ INJECTION WELL
- ● EXTRACTION WELL
- ☆ EXTRACTION/INJECTION WELL

000106

FINAL

FIGURE 5-5. MODELED GROUNDWATER ELEVATIONS FOR 1999 THROUGH 2003



LEGEND:

— · — · — FEMP BOUNDARY

- - - - - - HOMEOWNER PROPERTY BOUNDARIES

○ INJECTION WELL

● EXTRACTION WELL

☆ EXTRACTION/INJECTION WELL

FINAL

u:#5crw2#dgn#mapthor#dpth#brsr083.dgn

STATE PLANAR COORDINATE SYSTEM 1927

18-JUN-1997

FIGURE 5-6. MODELED GROUNDWATER ELEVATIONS FOR 2004 THROUGH 2005

000107

851

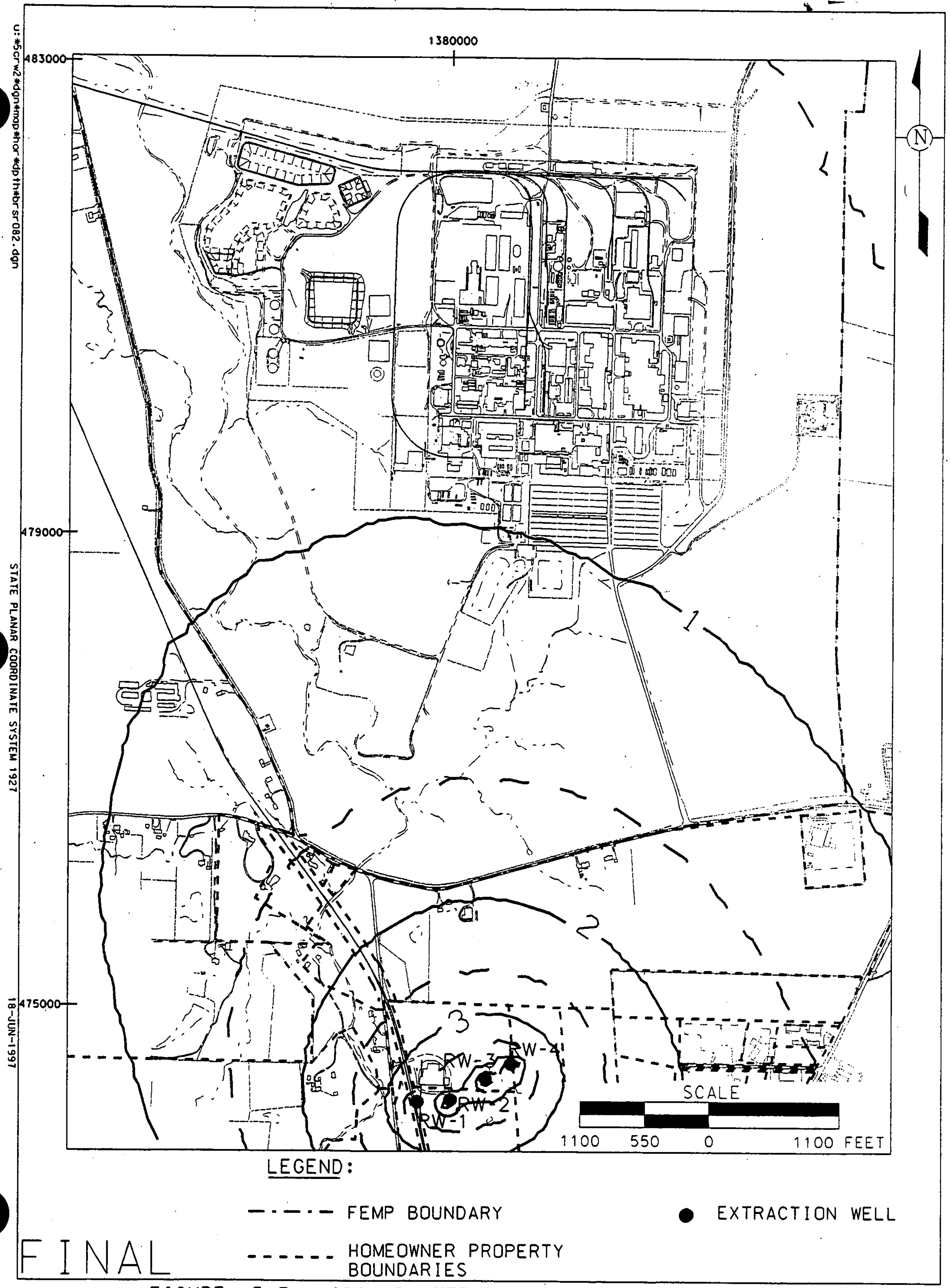


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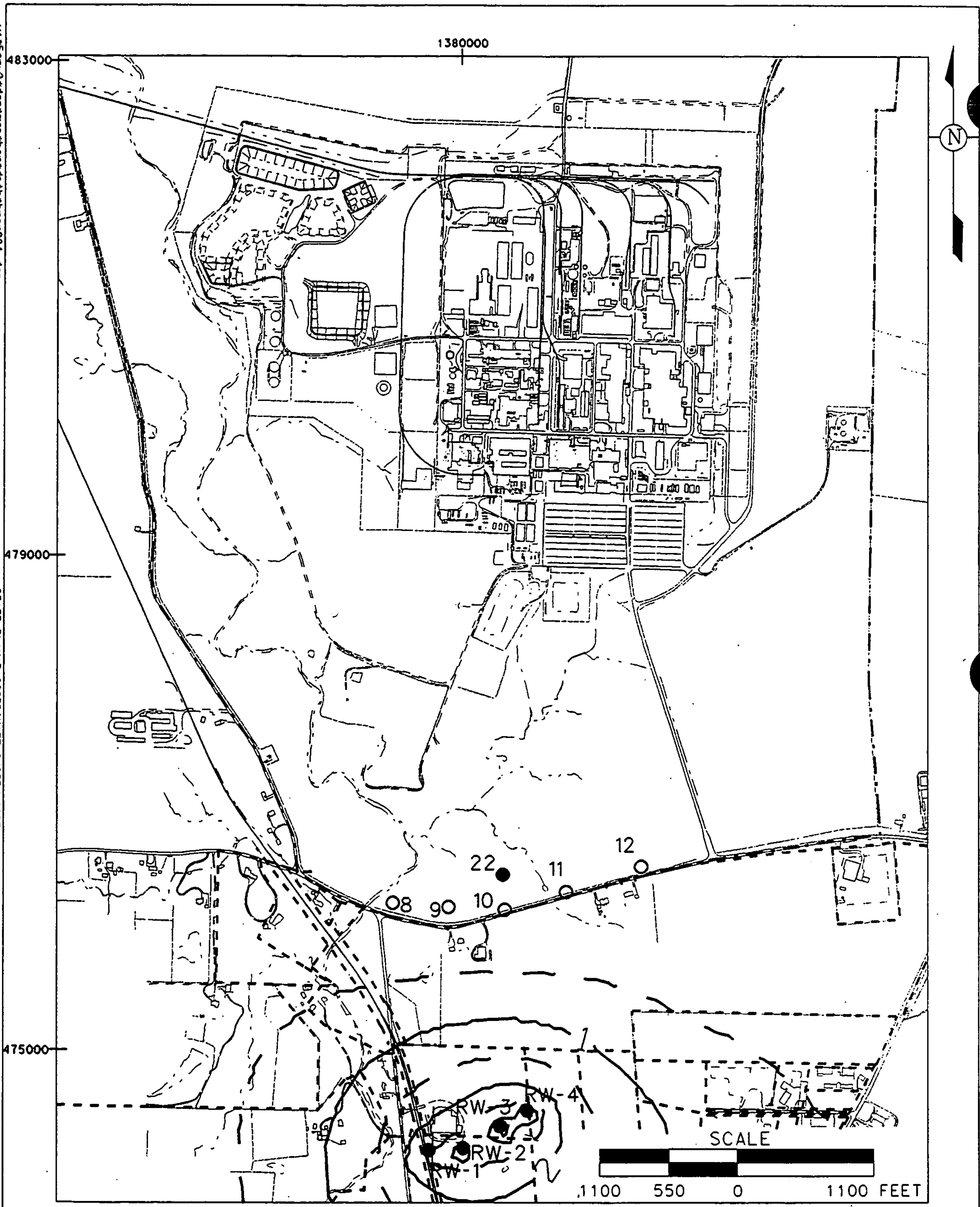
FIGURE 5-7. GROUNDWATER DRAWDOWN CONTOURS FOR 1997

000108



LEGEND:

FEMP BOUNDARY

HOMEOWNER PROPERTY BOUNDARIES

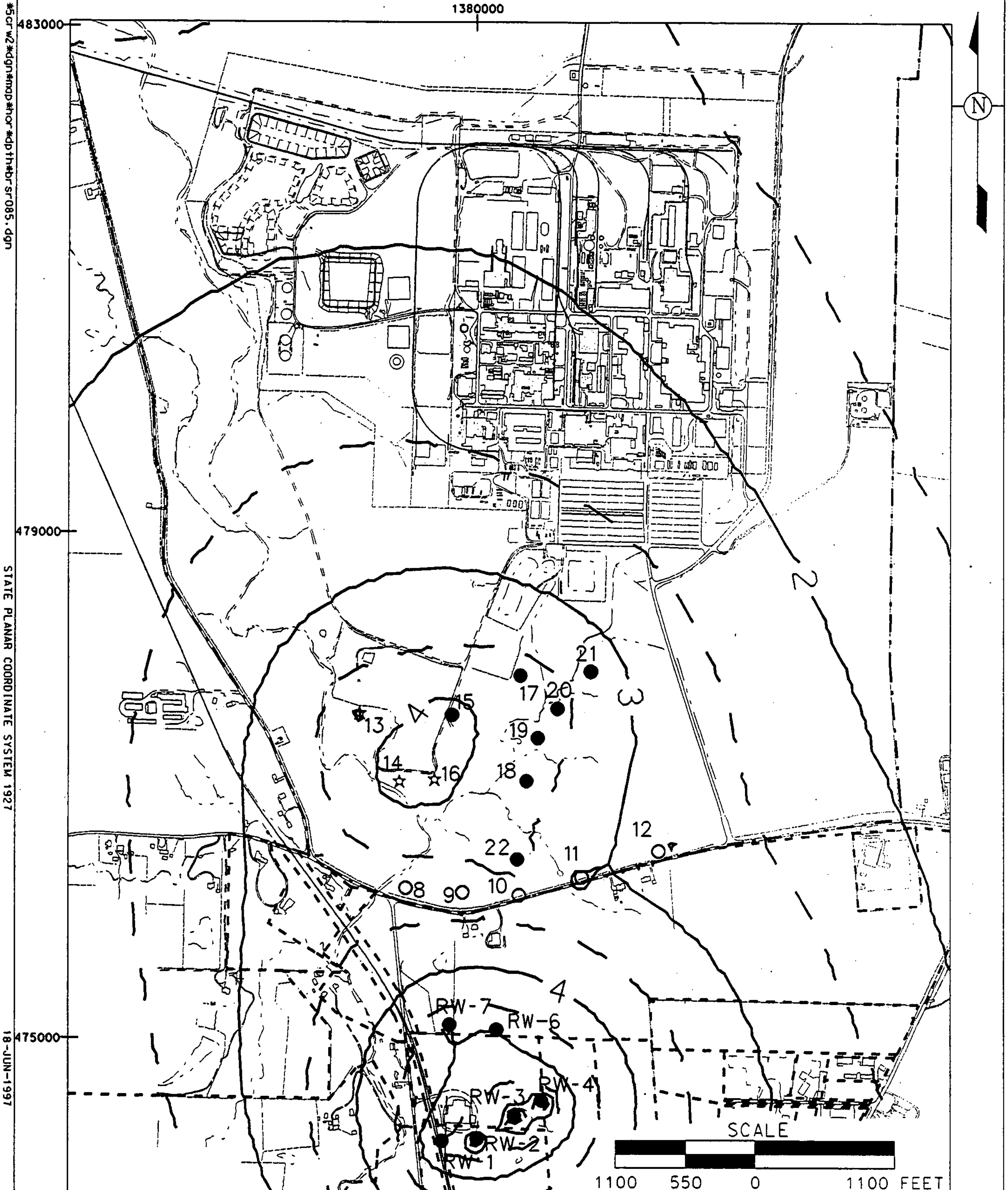
INJECTION WELL

EXTRACTION WELL

FINAL

FIGURE 5-8. GROUNDWATER DRAWDOWN CONTOURS FOR 1998

000109



LEGEND:

— · — · — FEMP BOUNDARY

- - - - - - HOMEOWNER PROPERTY BOUNDARIES

○ INJECTION WELL

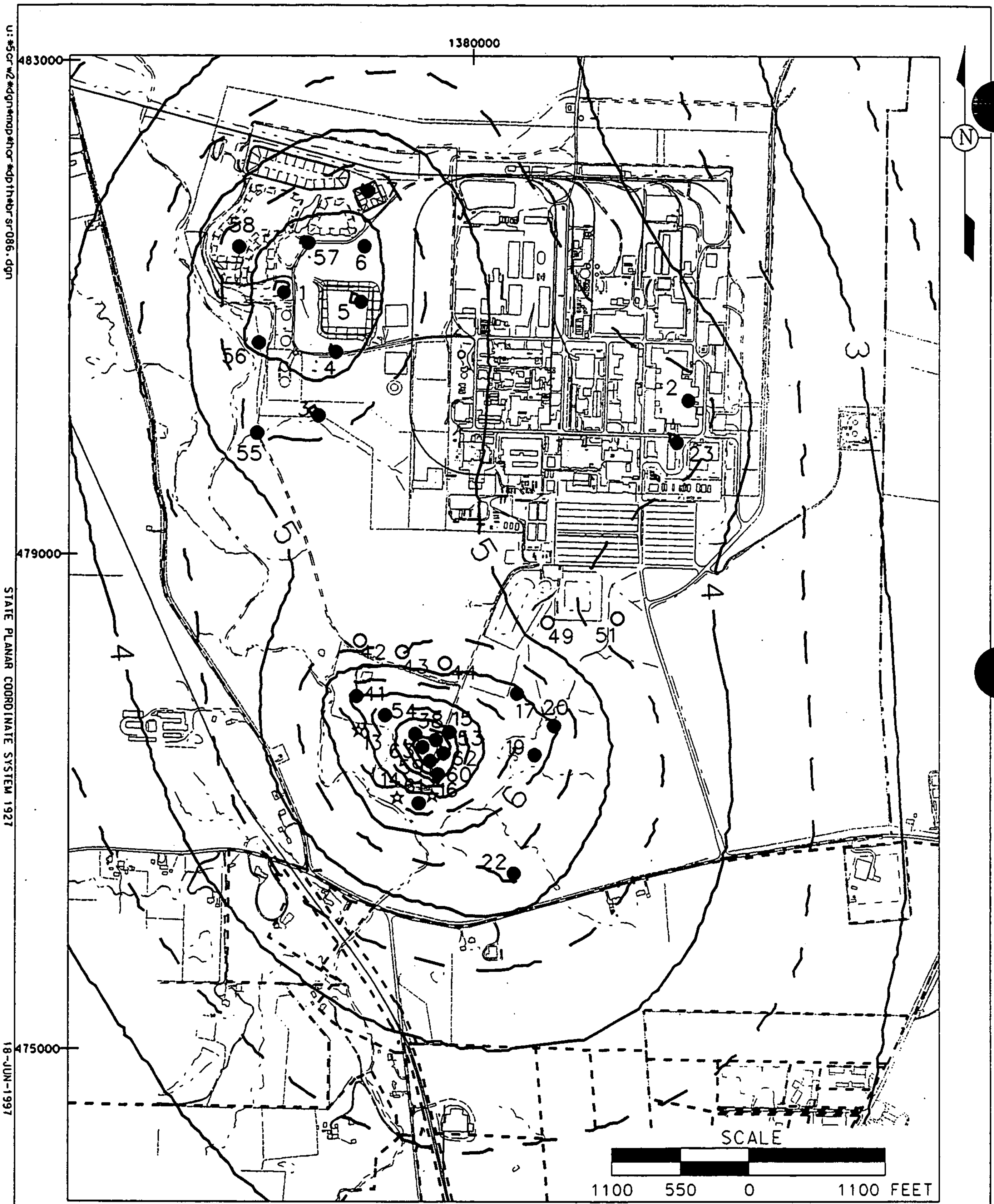
● EXTRACTION WELL

☆ EXTRACTION/INJECTION WELL

000110

FINAL

FIGURE 5-9. GROUNDWATER DRAWDOWN CONTOURS FOR 1999 THROUGH 2003



LEGEND:

FEMP BOUNDARY

HOMEOWNER PROPERTY BOUNDARIES

INJECTION WELL

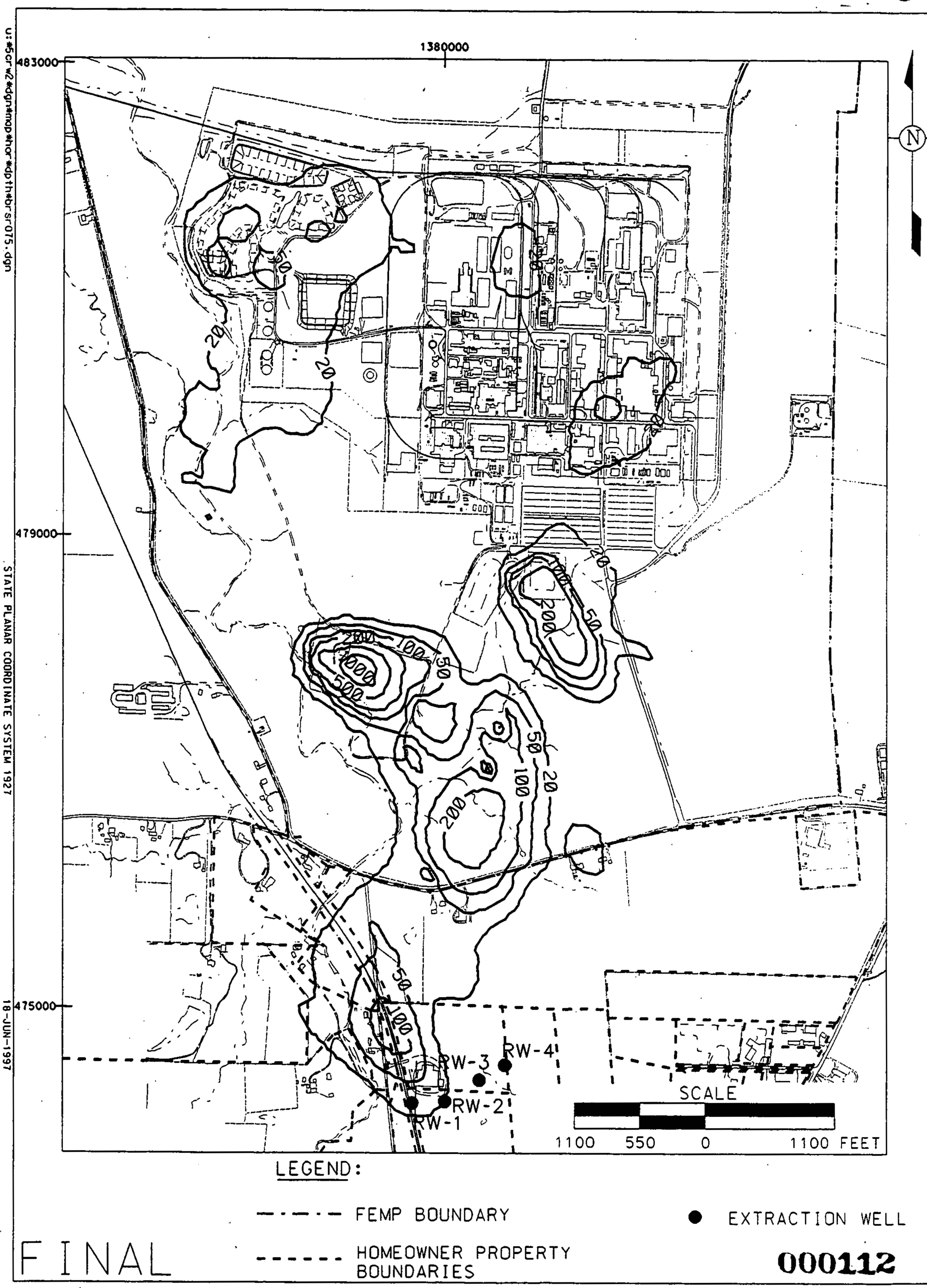
EXTRACTION WELL

EXTRACTION/INJECTION WELL

FINAL

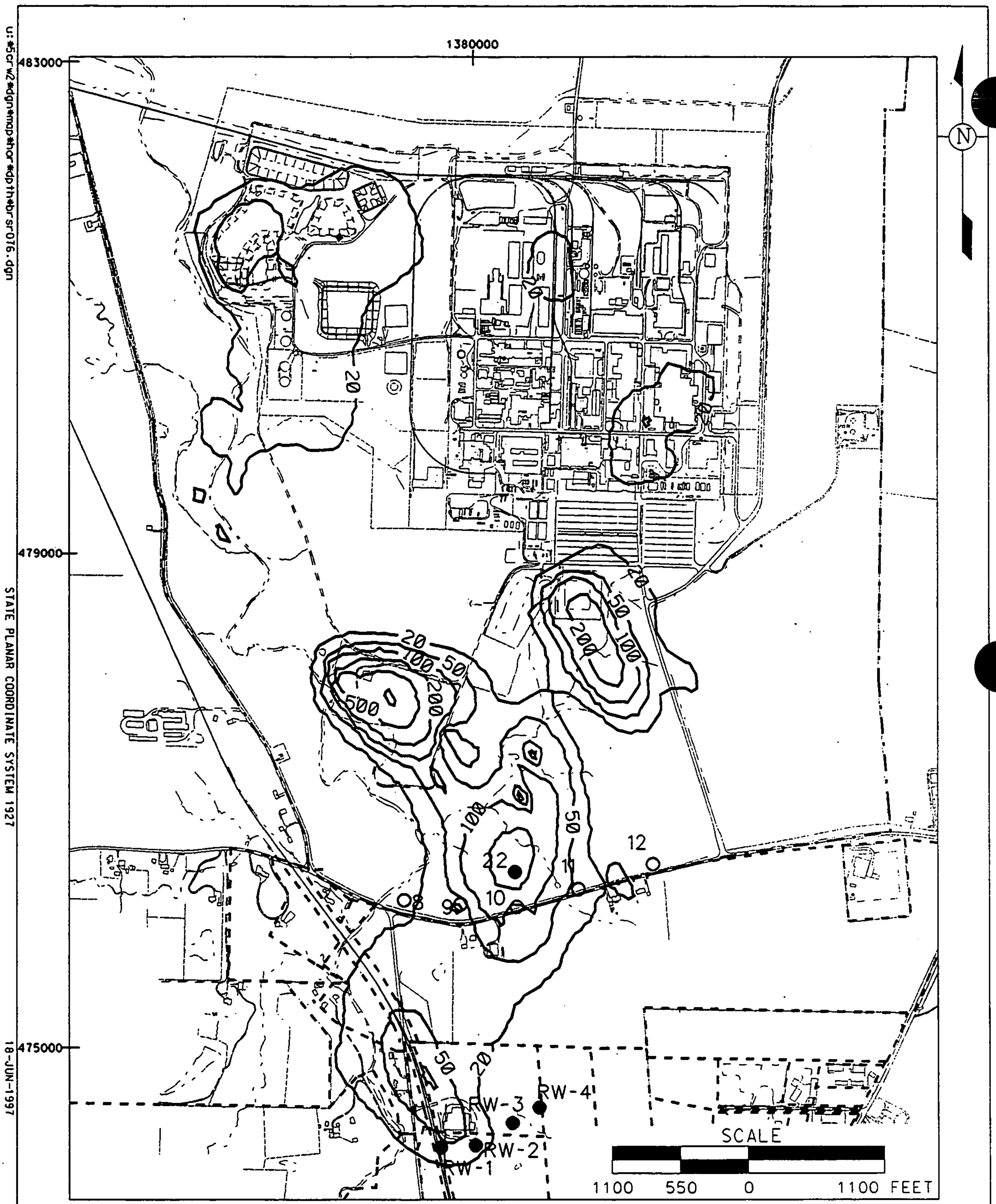
000111

FIGURE 5-10. GROUNDWATER DRAWDOWN CONTOURS FOR 2004 THROUGH 2005



000112

FIGURE 5-11. PROJECTED URANIUM CONCENTRATION CONTOURS FOR 1997



LEGEND:

-·-·- FEMP BOUNDARY

------ HOMEOWNER PROPERTY BOUNDARIES

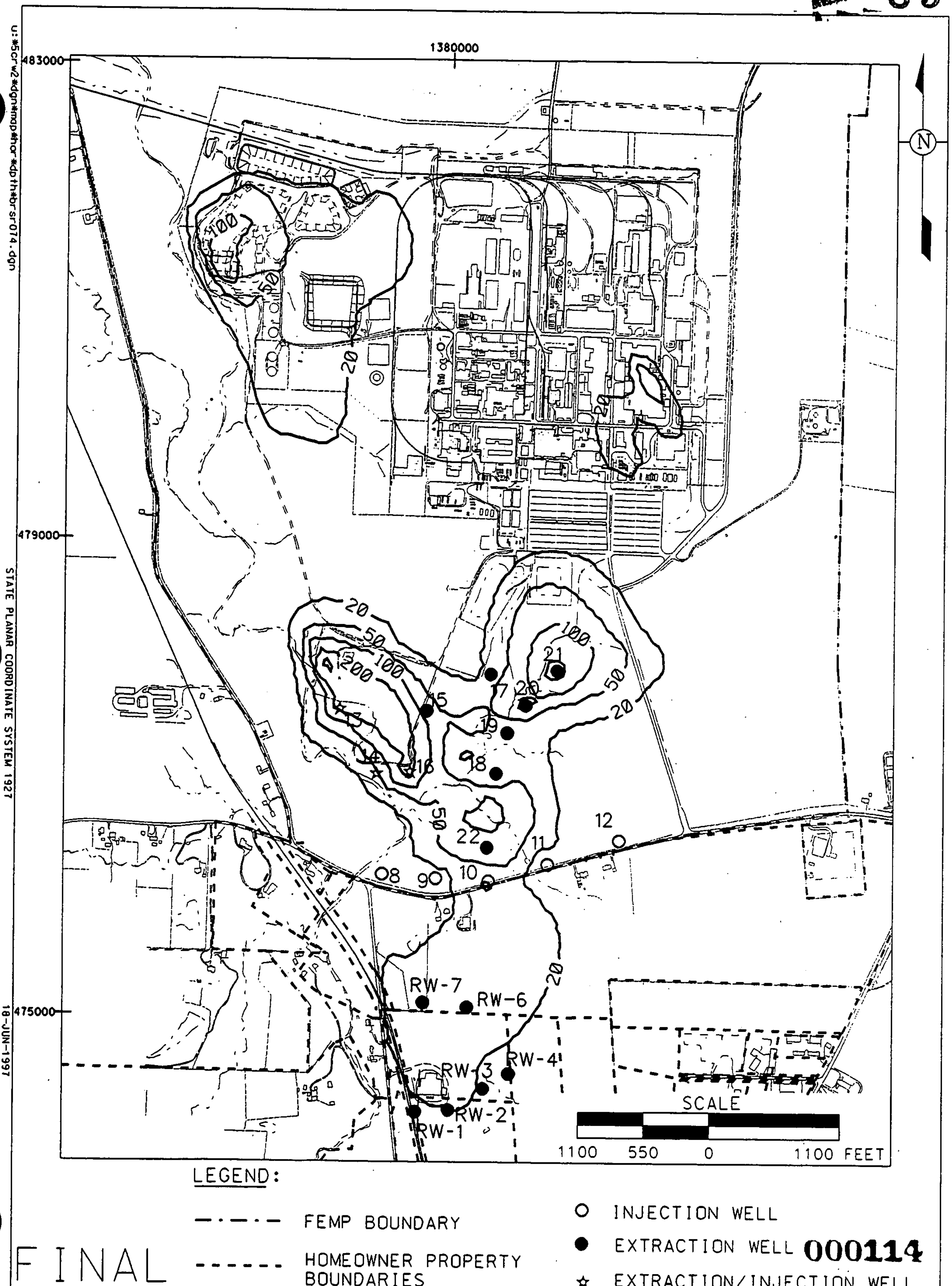
O INJECTION WELL

● EXTRACTION WELL

FINAL

FIGURE 5-12. PROJECTED URANIUM CONCENTRATION CONTOURS FOR 2013

000113



000114

FIGURE 5-13. PROJECTED URANIUM CONCENTRATION CONTOURS FOR 2003

TABLE 5-2
PERFORMANCE MEASURES FOR BASELINE GROUNDWATER REMEDIAL STRATEGY

Year	Total Water Pumped (gpm)	Treatment Capacity (gpm)	Water to Treatment (gpm)	Conc. to Treatment (ppb)	Water Not Treated (gpm)	Conc. not Treated (ppb)	Annual U Extracted from GMA (lbs)	Injected Water (gpm)	Conc. of Injected Water (ppb)	Annual Uranium Injected (lbs)	Water Discharged (gpm)	Conc. of Discharge (ppb)	Annual Uranium Discharged (lbs)	Total U Removed from GMA Annually (lbs)
1997	1400	400	400	13.0	1000	13.0	79.7	0	N/A	0.0	1400	10.7	65.7	79.7
1998	1600	2000	1600	44.2	0	0.0	309.6	1000	5.0	21.9	600	13.3	35.0	287.7
1999	3400	2000	2000	77.6	1400	19.4	797.9	1000	5.0	21.9	2400	13.4	140.6	776.0
2000	3400	2000	2000	79.8	1400	18.9	814.2	1000	5.0	21.9	2400	13.1	137.6	792.3
2001	3400	2000	2000	87.4	1400	18.6	878.4	1000	5.0	21.9	2400	12.9	135.6	856.6
2002	3400	2000	2000	92.9	1400	17.7	921.8	1000	5.0	21.9	2400	12.4	130.6	900.0
2003	3400	2000	2000	97.1	1400	16.4	950.7	1000	5.0	21.9	2400	11.7	122.6	928.9
2004	4800	2000	1650	27.7	3150	11.9	363.7	1600	5.0	35.0	3200	11.8	164.7	328.7
2005	4800	2000	1800	26.8	3000	9.8	340.0	1600	5.0	35.0	3200	9.5	133.5	304.9

Total U extracted from GMA (lbs)	5456.0	Total U Injected (lbs)	201.3	Total U removed from GMA (lbs)	5254.7

000115

TABLE 5-3

MASS OF URANIUM REMOVED BY MODULE DURING BASELINE GROUNDWATER REMEDIAL STRATEGY

	Mass Removed by Module (lbs)						
Year	System I	System II	System III	System IV	System IV-Opt	Injected Mass	Yearly Total
1997	N/A	N/A	N/A	79.7	N/A	0.0	79.7
1998	N/A	209.5	N/A	100.0	N/A	21.9	287.7
1999	N/A	618.0	N/A	99.6	80.3	21.9	776.0
2000	N/A	643.4	N/A	98.0	72.8	21.9	792.3
2001	N/A	717.9	N/A	87.7	72.8	21.9	856.5
2002	N/A	771.4	N/A	90.4	60.1	21.9	899.9
2003	N/A	810.2	N/A	86.3	54.2	21.9	928.8
2004	112.5	193.3	57.9	N/A	N/A	35.0	328.7
2005	116.0	164.3	59.6	N/A	N/A	35.0	305.0

System I = Waste Pit
System II = Production Area
System II = South Field (Phases I and II)
System IV = South Plume (RW-1, RW-2, RW-3, RW-4)
System IV-Opt = Wells RW-6 & RW-7

000116

8651

depicted in Figure 5-14. This extent was determined through the modeling simulations and represents a composite picture of the individual time steps of plume advance in both model layers 1 and 2. This composite maximum expansion, however, will still reside within (and therefore be controlled by) the hydraulic capture zone created by the existing South Plume recovery wells. The downgradient edge of this capture zone is also indicated in Figure 5-14. The complete hydraulic capture zone indicated by simulated particle tracks is shown in Figure 5-15. The complete capture zone of uranium indicated by simulated particle tracks with retardation effect is shown in Figure 5-16.

5.3.2 Uncertainty Analysis

As described in Section 1.3, a number of factors cause uncertainty in the actual time and resources necessary to successfully complete aquifer restoration. DOE, EPA, OEPA and other FEMP decision-makers need to fully understand the significance of the uncertainties in order to make well-informed decisions concerning how the program will be implemented both initially and at later stages of the cleanup.

The human factors (see Section 1.3.1) which can not be directly addressed in a quantitative uncertainty analysis were evaluated qualitatively when selecting the preliminary baseline strategy as discussed in Section 4.3.2. Impacts of two of the three major natural factors (i.e., hydraulic characteristics of the aquifer and geochemical conditions as described by the K_d parameter in the SWIFT model) on the recommended baseline remedial strategy as described in Section 5.2 were further evaluated in an uncertainty analysis which is summarized in Appendix F.

As described in Appendix F, the sensitivity of the projected system performance to aquifer hydraulic characteristics and geochemical conditions was first evaluated. The purpose of the sensitivity evaluation was to identify the critical parameters used in modeling to characterize these two factors. Critical parameters were identified based on parameter-specific uncertainties and expected impact to the modeling results within the parameter-specific uncertainty ranges. The critical parameters were then evaluated in the uncertainty analysis to quantify the ranges of potential cleanup time and cost. During the uncertainty analysis, three bounding scenarios were defined to bracket the plausible range of potential geochemical conditions.

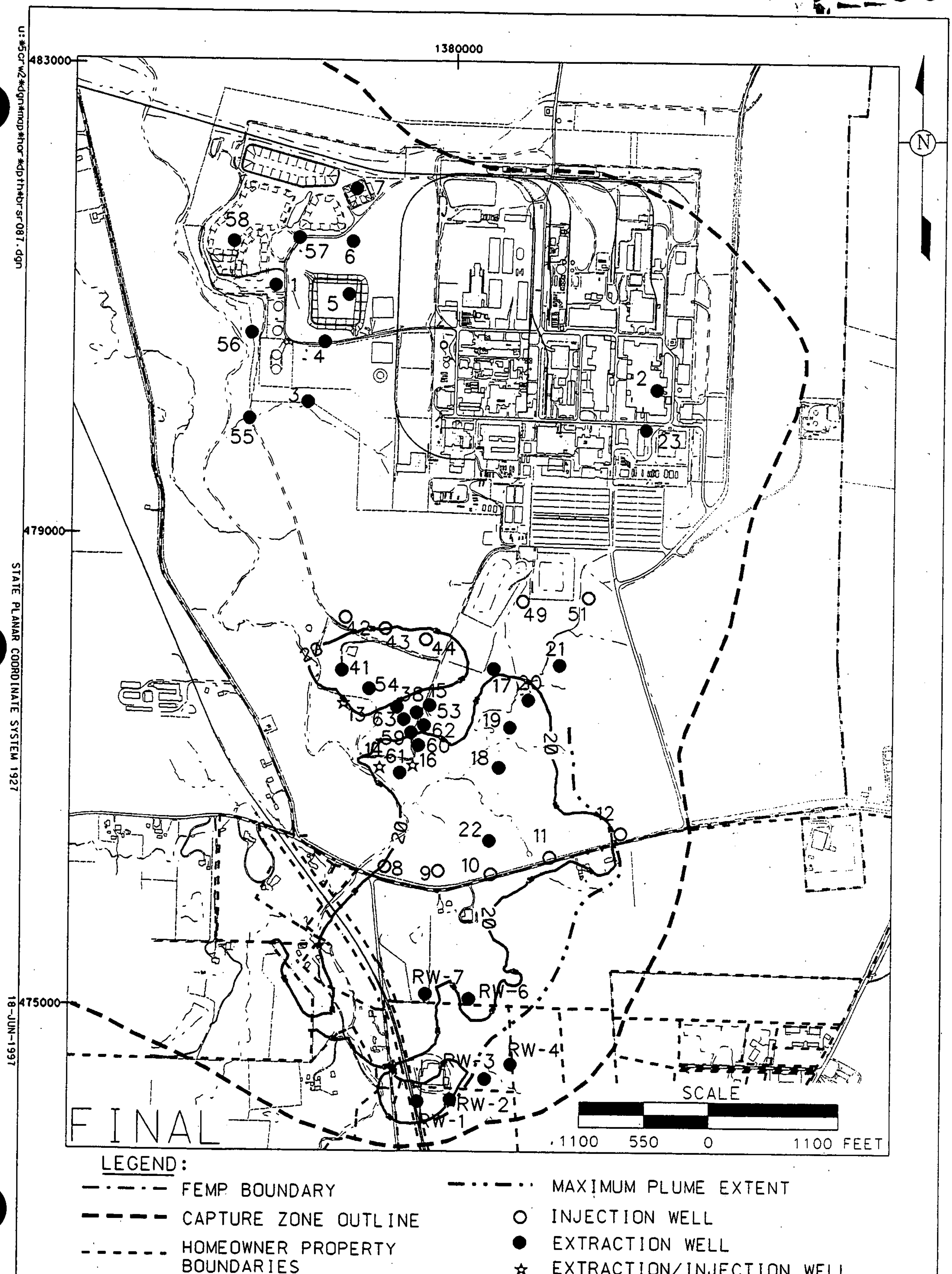
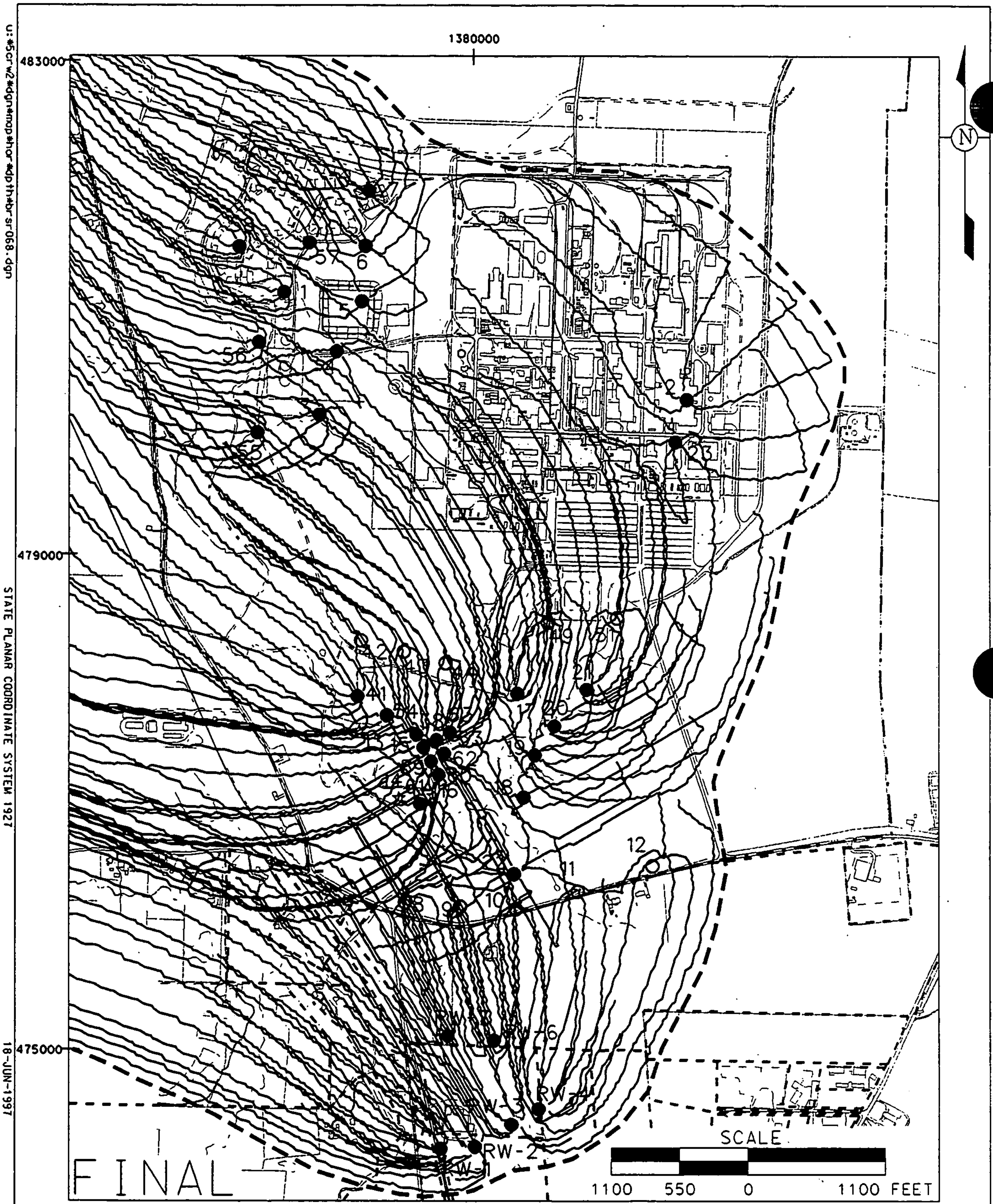


FIGURE 5-14. MAXIMUM EXTENT OF THE OFF-PROPERTY 20 ppb CONTOUR

000118



LEGEND:

- FEMP BOUNDARY
- CAPTURE ZONE OUTLINE
- HOMEOWNER PROPERTY BOUNDARIES
- ○ INJECTION WELL
- ● EXTRACTION WELL
- ☆ EXTRACTION/INJECTION WELL

FIGURE 5-15. COMPLETE HYDRAULIC CAPTURE ZONE **000119**

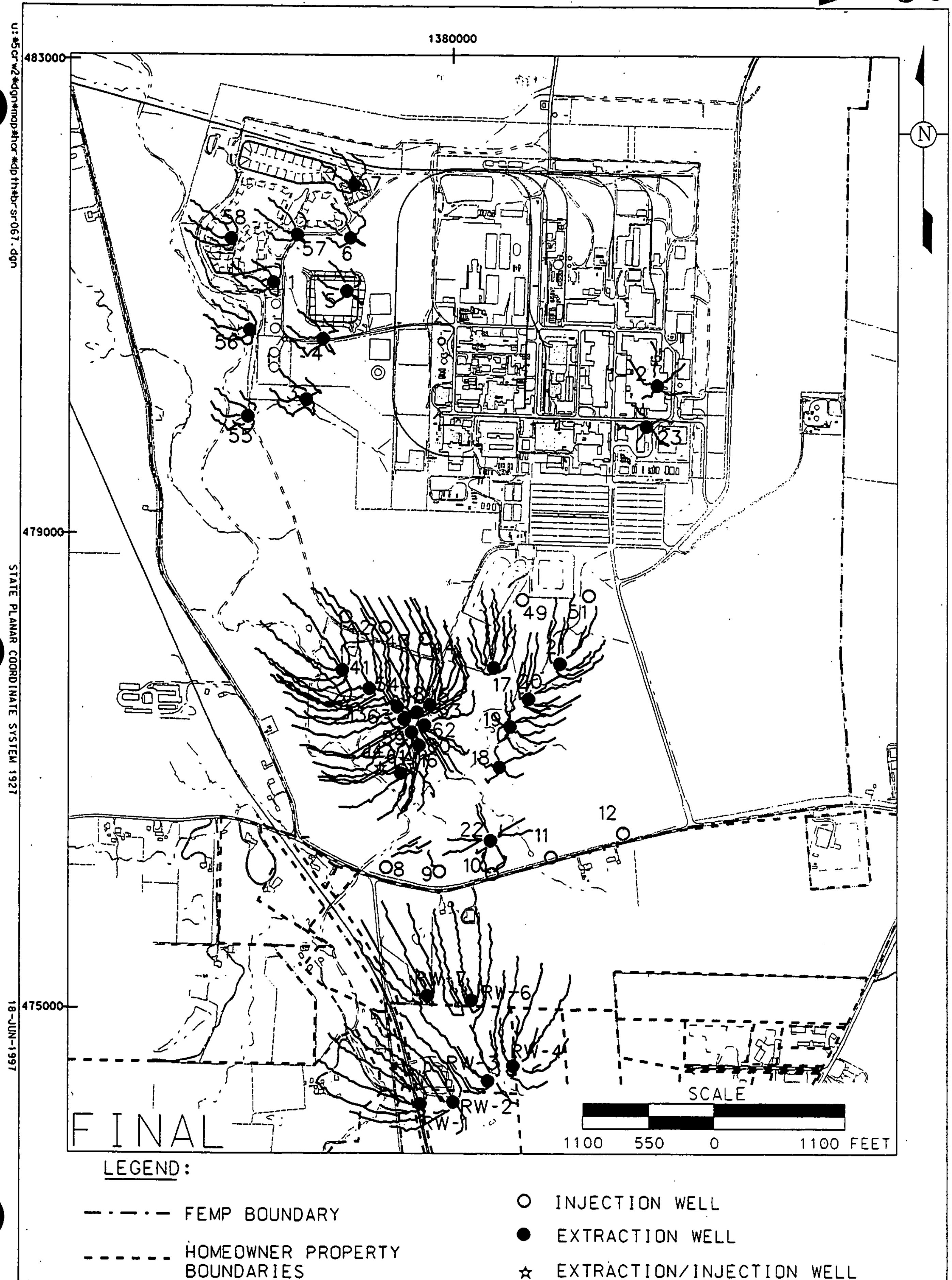


FIGURE 5-16. COMPLETE HYDRAULIC CAPTURE ZONE WITH RETARDATION

Results of the uncertainty analysis indicate that the range of the overall groundwater cleanup time using the recommended baseline remedial strategy should be between 10 to 20 years. Using the relative unit costs presented in Table 4-9, the overall cost of the aquifer remediation will be between 140 to 250 relative cost units (each unit is $500,000) based on the range of uncertainty in cleanup time. The difference between the lower and upper bounds primarily includes 10 years of groundwater treatment operation and monitoring and reporting activities after all the other FEMP source remedial activities are completed.

It is difficult to quantify potential deleterious effects of iron bacteria on the long-term success for the groundwater injection operation. If the expected benefits of groundwater injection do not materialize due to iron precipitation problems, the actual groundwater cleanup time may not be significantly shorter than the 27 years time frame estimated in the Operable Unit 5 FS.

Based on the best available information, the projected performance of the recommended baseline remedial strategy as presented in Section 5.3.1 is considered the most likely path in which the groundwater remediation at the FEMP will progress. Strategies for dealing with the less likely conditions (such as those evaluated in the uncertainty analysis), should they manifest themselves during the remedial operation, are discussed in Section 5.4.5.

5.4 GENERAL OPERATIONAL STRATEGY

In addition to the properly designed extraction/injection well systems, success of the Aquifer Restoration Project as part of the overall FEMP remediation will also rely on a realistic operational strategy which considers other major remediation activities at the FEMP. This subsection provides the critical operating guidelines during aquifer restoration.

5.4.1 General Principles

Requirements for achieving the performance goals of different FEMP remedial actions may compete for the same resources or may occasionally lead to conflicting operating decisions during remediation. Therefore, it is important to develop a general operating priority. The main potential conflict among aquifer restoration, storm water/waste water management, and wastewater treatment will be the treatment decision between storm water runoff and extracted groundwater. The general principles that will be followed to resolve these conflicts are the following:

- Compliance with the outfall criteria (NPDES and ROD commitments) will be the dominant regulatory requirement during the FEMP remediation
- Minimizing potential spreading of contaminants in the surface pathways (i.e., air, surface water, and sediment) caused by remediation activities is also one of the most important requirements for each of the FEMP remediation projects (so supporting the surface source control efforts is important)
- Allow duration of surface remediation involving open excavation, construction, or storage activities to be minimized (so supporting the on-going surface remediation activities is important)
- Uncontrolled storm water runoff concentrations should not be worse than the current conditions
- Available treatment capacity should be fully utilized.

5.4.2 Baseline Treatment Priorities

Due to the limited storm water retention basin (SWRB) capacity (for a 10-year, 24-hour storm event over the production and parking lot areas), collection of storm water runoff from areas with potentially higher contaminant concentrations in runoff (based on soil contaminant concentrations) should be given higher priority. This may involve adjustments of the storm water control area with the progression of the soil remediation and construction projects. Currently the storm water control system covers both the production and waste pit/silo areas where runoff contaminant concentrations are consistently higher than the remaining FEMP property.

Due to the higher contaminant concentrations expected in remediation wastewater and storm water runoff from source areas, treating remediation wastewater and storm water runoff will be given higher priority than treating the extracted groundwater. Therefore, the total groundwater extraction rate will be throttled down when the available treatment capacity can not handle all three types of inflows and satisfy the outfall criteria. When groundwater extraction rate needs to be throttled down, remediation of the off-property groundwater plume should have higher priority.

Currently, the combined uranium concentration in the extracted South Plume groundwater is less than 20 ppb. This extracted groundwater flow does not require treatment to satisfy the outfall criteria. Therefore, the baseline priority does not impact the current operation of the groundwater remediation. However, when the initial South Plume Optimization Module and the South Field Extraction System start operation in FY99, extracted groundwater will require treatment. Groundwater extraction rate and treatment decisions will be affected during the wet seasons when storm water runoff volume is significant.

5.4.3 Groundwater Extraction And Injection Rate Determination

Table 5-1 summarizes the groundwater extraction/injection rate schedule based on assumptions regarding available groundwater treatment capacity. During the remediation, available groundwater treatment capacity will be determined using actual treatment capacity, and after storm water runoff and remediation wastewater treatment needs are met. Computer modeling will then be conducted to determine the optimal groundwater extraction rate for the extraction wells still within the uranium plume by maximizing the flow rate up to the originally planned rate and uranium mass that can be handled by the available treatment capacity and still satisfy the outfall criteria. Uranium concentrations of the extracted groundwater and the combined outfall will be projected in the modeling process. The model simulations will include groundwater injection when the injection wells are on-line. After the outfall criteria are satisfied, remaining available treated groundwater will be quantified and used in the injection operation. The projected capture zone and other hydraulic impacts will also be determined and documented.

In order to support the extraction/injection rate determination, validity of the Great Miami Aquifer groundwater model developed through the RI/FS process will be periodically evaluated and updated using the groundwater monitoring data collected during the remediation.

5.4.4 Modes Of Operation

Depending on the actual treatment capacity/performance and climatological conditions, there will be three major modes of operation of the groundwater remediation and wastewater treatment systems during the FEMP remediation. Operating procedures for these three modes will be developed separately during the remedial design process. This subsection describes the general approaches of operation under these three modes.

5.4.4.1 Normal Mode

The expected normal operational mode is when the treatment capacity and the storm water/wastewater generation rate are close to the projected long-term average levels, respectively. Under the normal mode, groundwater remediation systems can be operated as planned and the outfall criteria can be satisfied. The normal operational mode represents a realistically achievable operational condition and will be maintained as much as possible throughout the life of the FEMP remediation.

5.4.4.2 Emergency Bypass Mode

During abnormal storm events, a portion of the collected storm water runoff may need to bypass treatment and be directly discharged to the Great Miami River to prevent overflow of the SWRB into the SSOD. The current outfall criteria allow 10 days (240 hours) in each year for emergency discharge of high storm water runoff. Groundwater extraction rates will be throttled down when the IAWWT treatment capacities need to be used for treating remaining storm water in the SWRB until the threat of overflow is eased. Because of the higher uranium concentrations, extraction rate of the on-property groundwater remediation modules will be lowered first to reduce the demand for treatment capacity. This will also allow the off-property groundwater remediation schedule to be maintained.

5.4.4.3 Insufficient Treatment Performance Mode

When the treatment capacity or efficiency (measured by uranium concentration in the treated water) drops significantly below the planned capacity due to technical problems for more than two weeks (i.e., 50 percent of the monthly evaluation period), groundwater extraction rates will need to be throttled down to ensure compliance with the monthly outfall criteria. The optimal lower extraction rates will be determined by model simulation. The technical problems will need to be corrected as soon as possible.

5.4.5 Continuous Performance Assessment and System Improvement

Based on the best available information and the most reasonable assumptions regarding site-specific hydrogeological, geochemical, and groundwater contamination, the selected remedial strategy presents the "optimal" starting point of the detailed engineering design process and the full-scale groundwater remediation at the FEMP. However, due to the complex nature of groundwater contaminant fate and transport processes, a continuous improvement process based on EPA's "learn as you go" guidance (EPA 1992) will also be applied during the long-term operation of the remedial system. The Integrated Environmental Monitoring Plan (defined as Task 9 in the Operable Unit 5 RD Work Plan) will incorporate data collection and evaluation procedures necessary for continuous performance assessment and system improvement.

As described in Appendix F, although the bounding geochemical conditions simulated in the uncertainty analysis are significantly different from the baseline scenario, in order to simplify the uncertainty analysis only minor modifications to the original extraction/remediation rate schedule (see Table 5-1) using the wells included in the recommended baseline strategy were considered. Given the uncertainty of system performance, the operating situations (and accompanying remedial decisions) as described in Section 1.4 may develop. At some point in the future, as actual operating conditions are experienced and performance results are obtained, the FEMP's primary decision-makers (DOE, EPA, OEPA, and affected stakeholders) may be confronted with a need to modify the operating strategy of the groundwater remedy from that recommended initially by this report.

As stated in Section 1.4, tradeoff evaluations could be necessary during groundwater remediation and such tradeoffs will need to consider both the physical capabilities of the system and the most cost-effective path forward. The preferred course for some situations may result in adding additional infrastructure (resulting in increased capital cost) in order to preserve desired cleanup times and/or avoid additional long-term operational costs. In other cases, the preferred course may result in the need to extend cleanup time as the fiscally responsible decision. These decisions will need to be made on a case-by-case basis based on the physical and cost constraints imposed (recognizing DOE's programmatic objective to reduce site mortgage costs as tempered by available funding profiles), and under the collective agreement of DOE, EPA, OEPA, and affected stakeholders.

5.4.6 Contingency South Plume Optimization Well

The previous section describes the general approach for continuous performance assessment and improvement of the aquifer remedial system. As a result of the resolution of the off-property landowner access issues, the South Plume Optimization Module now includes a contingency well (i.e., Well 3N to be renamed as "RW-8"). Therefore, a specific approach for assessing the need for the contingency well at a later date is required by EPA and OEPA as part of the baseline remedial strategy. Reasonable technically-based contingency triggers based on actual future conditions that may result in the need to install Well 3N (either at its originally proposed location or a potential new location) include the following:

- The off-property uranium plume expands beyond the actual capture zone of the initial overall South Plume System;
- Significant cross-fenceline migration of the on-property uranium plume occurs due to ineffective injection well operations along the FEMP fenceline;
- New uranium hot spots with significantly higher concentrations are identified far away from the initial recovery wells;
- Concentrations in most of the off-property groundwater monitoring wells quickly reach asymptotic values above the groundwater FRL even after adjusting the extraction rates of the existing wells (i.e., higher rates and/or pulsed pumping); and
- The actual FEMP outfall uranium concentrations are constantly lower than the limit (i.e., 20 ppb) even after increasing the extraction rates of existing wells in the hot spots (i.e., RW-6, RW-7, and Well 22) to full capacity (i.e., 400 gpm per well).

In order to facilitate early detection of the above conditions, the necessary start-up monitoring activities for tracking important indicator parameters will be identified and included in Project Specific Plans for the South Plume Optimization and the Groundwater Injection Demonstration Modules. As outlined in the Operations and Maintenance Plan for the Aquifer Restoration and Wastewater Treatment Projects (defined as Task 2 in the Operable Unit 5 Remedial Design Work Plan (DOE 1996) and scheduled for submittal to EPA and OEPA in July, 1997), these plans will be provided to the EPA and OEPA for input and approval prior to system start-up for each module. Once conditions have stabilized, any modifications to the long-term groundwater monitoring approach arising from the start-up monitoring will be incorporated into the IEMP as necessary (see page 3-74 of the IEMP [DOE 1997]), as part of the formal IEMP 2-year revision process.

After the occurrences of any or combinations of the above listed conditions are confirmed, the optimal location and operational condition of the contingency well (and the potential need for a separate discharge line) would be determined based on actual remedy performance data assembled, modeling simulations incorporating the new data, and the consideration of landowner access preferences and constraints. If deployment of the well is determined to be beneficial and feasible, the procedure for incorporating the contingency well as an add-on restoration module ("South Plume Optimization II") as described in Section 5.2.1.2 will be followed.

Section 6.0

6.0 CONCLUSIONS

6.1 SUMMARY OF THE RECOMMENDED BASELINE REMEDIAL STRATEGY

The baseline groundwater remedial strategy to be used as the basis of the remedial design process has been developed. The development process started with a preliminary evaluation focusing on cost-effectiveness of a range of potential improvements to the FS strategy with simplified assumptions regarding funding and off-property access. A preliminary 10-year baseline strategy was selected at the end of the preliminary evaluation. The baseline strategy was finalized by incorporating necessary modifications after considering the updated uranium plume, the actual funding schedule, and off-property access limitations imposed by the landowner.

6.1.1 System Configuration

When compared to the remedial strategy presented in the Operable Unit 5 FS Report (DOE 1995a), the following modifications have been included in the selected preliminary baseline strategy:

- Groundwater injection along the fence line and north of the South Field will be used to improve hydraulic performance of the remediation system. The fence line system (converted from Wells 8 through 12 in the FS Strategy) will start operation in FY98 while the upgradient system (5 new injection wells) will start before FY04. Only treated groundwater will be use for injection.

- Well 17 in the FS Strategy is moved to a new location north of the SSOD.

- Well 22 in the FS Strategy is moved to a new location based on the new Geoprobe sampling results to reduce further cross-fenceline migration of uranium plume and to increase mass removal efficiency of the South Field Phase I Module in the area south of the SSOD.

- Two additional off-property extraction wells (with the potential of a third well in the future pending actual system performance and four of the existing South Plume wells will be used to optimize the South Plume Recovery Well System.

- Nine more vertical extraction wells in the Inactive Flyash Pile, four more vertical extraction wells in the Waste Pit area, and one more vertical extraction well in the Plant 6 area will be installed and operated immediately following completion of local surface remediation or by FY04.

- Three of the initial extraction wells around the Inactive Flyash Pile will be converted into injection wells after the South Field Phase II System wells are installed.

Overall 45 wells are included in the selected preliminary baseline strategy. The number of wells is 17 more than the number in the FS Strategy.

To meet groundwater injection requirements and satisfy outfall discharge criteria, a groundwater treatment capacity of 2000 gpm will be required. This capacity will be available in early 1998 following the completion of the AWWT expansion, which has been selected as the lead project for implementation under FY97 funding constraints.

6.1.2 Projected Performance

The recommended baseline strategy, the modified 10-year scenario, incorporates groundwater injection and additional off-property extraction wells. Shorter remediation schedules for other operable units under the 10-year site-wide remediation plan allow earlier starts of groundwater extraction operations directly in the groundwater hot spots with additional vertical extraction wells. It is expected that the recommended baseline strategy can shorten aquifer restoration time by seven to 17 years, considering geochemical uncertainties (see Appendix F for an analysis of the uncertainties associated with this restoration time). This is a significant reduction from the estimated 27 years presented in the Operable Unit 5 FS Report. As a result the overall cost of aquifer restoration may be reduced by approximately 50 percent from that estimated in the Operable Unit 5 FS, primarily due to the shorter remediation time. This reduction is partially due to a more realistic transition of the K_d values used in the groundwater model to evaluate system performance. In general, higher mass removal efficiency will be achieved with more direct groundwater extractions at the hot spots. The stress on the aquifer and potential impacts to the Paddys Run Road Site will be reduced by using groundwater injection. Also, less uranium mass will be discharged to the Great Miami River due to the higher removal efficiency and the lower overall volume of groundwater needing to be extracted. In summary, all the regulatory requirements and previous commitments are satisfied in the recommended baseline strategy.

6.1.3 System Implementation Flexibilities

It is important to highlight that the 10-year, 15-year, and 25-year scenarios do not differ in terms of remedial infrastructure until year seven, which is the year that source-area remediation is assumed to be complete. The scenarios begin to differ at that point in terms of the number and location of followup wells and operating schedules. This consideration is important because all three scenarios start with the same initial remedial hardware, and followup decisions regarding out-year infrastructure do not need to be made until some point in the future. This preserves an additional element of implementation flexibility, as decision-makers are not really eliminating other options with the decision to implement the 10-year strategy as the starting baseline system.

On the other hand, the 7.5-year scenario eliminates such flexibility because it requires a commitment to totally different infrastructure at initial implementation. The 7.5-year scenario represents a bounding case to demonstrate the technical difficulties of going to a less than 10-year cleanup.

6.2 PATH FORWARD

6.2.1 Remedial Design and Remedial Action

Six fundamental objectives have been formulated for the Great Miami Aquifer remedial design process:

- Accommodate the need for sequential restoration modules, each independently designed, installed, and operated using "learn as you go" principles over the life of the remedy
- Build into the remedy the necessary enhancements and improvements (i.e., injection) that were envisioned by the Operable Unit 5 FS and ROD Reports
- Develop a sound remedial approach that will accomplish remedial action objectives within the aggressive time frames contained in the FEMP's current funding baseline
- Accommodate the transition of the existing infrastructure and early start actions into a coördinated site-wide final remedy
- Satisfy discharge limits for the release of groundwater, storm water, and remedial wastewater to the Great Miami River
- Restore the off-property portion of the Great Miami Aquifer groundwater plume as the FEMP's highest groundwater priority.

In order to fulfill these objectives, a remedial design process that extends over the life of the remedy is required. The remedial design scope of work reflects the need to prepare stand-alone design packages for each of the area-specific restoration modules that will ultimately be brought on line.

The delivery dates for each of the design packages have been estimated based on groundwater modeling projections of the behavior of the system over the entire life of the remedy. These projected dates represent the DOE's best technical estimates for when design submittals will be necessary. It is important to be clear, however, that the "in-the-ground" performance of the system, once the various modules come on line, will dictate the actual dates for when the out-year design packages will be necessary.

The Amended Consent Agreement requires preparation of a remedial action work plan to cover construction activities and the establishment of an enforceable RA schedule. Initially an "umbrella" RA Work Plan will be submitted to provide all information required by the Consent Agreement and to convey the enforceable construction schedule for the first module to be brought on line. Then an abbreviated addendum to the RA Work Plan will be submitted for each successive module as a means of providing the enforceable construction schedule for that module. The RA Work Plan addenda will be furnished as part of the prefinal design package for each future module and will be tailored to address module-specific implementation issues and needs.

6.2.2 Operations and Maintenance Plan

Under Task 2 of the RD Work Plan, A master Operations and Maintenance Plan will be developed as a means to coordinate the extraction, collection, conveyance, treatment, and discharge of all groundwater, storm water, and remediation wastewater generated on a site-wide basis over the life of the FEMP's cleanup mission. The general operational strategy for aquifer restoration discussed in Section 4.4 will be incorporated in this plan. Preventative and corrective maintenance requirements for the extraction/injection well systems specified in the baseline strategy will be presented in the plan.

The plan will also serve as the focal point for coordinating and scheduling remedial wastewater conveyance and treatment needs with other projects throughout the duration of the FEMP's cleanup mission. The plan will delineate the operating schedule, allowable direct discharge and treated water flow rates, system-by-system sequencing, and other operating constraints required to balance site-wide water management needs so that the FEMP's discharge limits are achieved. The plan will be modified as necessary over the life of the remedy to accommodate expansions to the system or the retiring of individual restoration modules from service once area-specific cleanup levels are achieved. The plan will thus serve as a living guidance document to instruct operations staff in implementing required adjustments to the system over time.

6.2.3 Process for Future Remedial Performance Decisions

As outlined in Section 1.4, the recommended strategy presented in this Baseline Remedial Strategy Report provides a recommended course of action based on the best understanding of site conditions available at this time. It is important to emphasize that the recommendation does not specify an enforceable restoration time frame that must be achieved at all costs. Rather, it identifies a preferred restoration time frame based on the anticipated behavior of the aquifer and the expected performance and cost of the remedial components, consistent with EPA groundwater guidance.

At some point in the future, as actual operating conditions are experienced and performance results are obtained, the FEMP's primary decision-makers (DOE, EPA, OEPA, and affected stakeholders) may be confronted with a need to modify the operating strategy from that recommended initially by this report. The type of modifications, administrative actions, and/or hardware decisions will need to be assessed on a case-by-case basis based on the unique physical and cost constraints imposed. A cost/benefit analysis (similar to the one provided in this report) can be used to help establish an appropriate technical or administrative path forward. That path forward may involve an extension of restoration time, the addition of more wells to maintain restoration time, or the ultimate granting of a TI waiver based on the conditions experienced.

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References

REFERENCES

Alm, A. L., 1996, "Integrated Strategic Planning, Budgeting and Mgmt. System/10-Year Planning," Memorandum dated June 10, 1996, from Asst. Secretary for Env. Mgmt., U.S. Department of Energy, Washington, D.C.

Di Toro, D. M. and L. M. Horzempa, 1982, "Reversible and Resistant Components of PCB Adsorption-Desorption dated Sept. 1982, vol. 16, p. 594," Congressional Information Service, Inc., U.S. Dept. of Energy, Washington, D.C.

Di Toro, D. M. and L. M. Horzempa, 1983, "PCB Partitioning in Sediment-Water Systems: the Effect of Seciment Concentration, July-Sept. 1983, vol. 12, p. 373," Congressional Information Service, Inc., U.S. Dept. of Energy, Washington, D.C.

Lasaga, A. C., 1981, Rate Laws of Chemical Reactions, in Reviews in Mineralogy, Volume 8, Kinetics of Geochemical Processes, A.C. Lasaga and R.J. Kirkpatrick, eds., Mineralogical Society of America, Washington, D.C.

U.S. Department of Energy, 1993a, "Groundwater Modeling Report - Summary of Model Development," Fernald Environmental Management Project, DOE, Fernald Area Office, Cincinnati, OH.

U.S. Department of Energy, 1993b, "South Plume Removal Action Pumping Test Report," Fernald Environmental Management Project, DOE, Fernald Area Office, Cincinnati, OH.

U.S. Department of Energy, 1994, "SWIFT Great Miami Aquifer Model - Summary of Improvements, Report," Fernald Environmental Management Project, DOE, Fernald Area Office, Cincinnati, OH.

U.S. Department of Energy, 1995a, "Feasibility Study Report for Operable Unit 5," Final, Fernald Environmental Management Project, DOE, Fernald Area Office, Cincinnati, OH.

U.S. Department of Energy, 1995b, "Proposed Plan for Operable Unit 5," Fernald Environmental Management Project, DOE, Fernald Area Office, Cincinnati, OH.

U.S. Department of Energy, 1995c, "Remedial Investigation Report for Operable Unit 5," Final, Fernald Environmental Management Project, DOE, Fernald Area Office, Cincinnati, OH.

U.S. Department of Energy, 1995d, "South Field Pumping Test Report," Fernald Environmental Management Project, DOE, Fernald Area Office, Cincinnati, OH.

U.S. Department of Energy, 1995e, "South Field Injection Test Report," Fernald Environmental Management Project, DOE, Fernald Area Office, Cincinnati, OH.

U.S. Department of Energy, 1996a, "Record of Decision for Remedial Actions at Operable Unit 5," Final, Fernald Environmental Management Project, DOE, Fernald Area Office, Cincinnati, OH.

U.S. Department of Energy, 1996b, "Remedial Design Work Plan for Remedial Actions at Operable Unit 5," Draft Final, Fernald Environmental Management Project, DOE, Fernald Area Office, Cincinnati, OH.

U.S. Department of Energy, 1996c, "Integrated Environmental Monitoring Plan," Draft, Fernald Environmental Management Project, DOE, Fernald Area Office, Cincinnati, OH.

U.S. Department of Energy, 1996d, "South Plume Removal Action Design Monitoring Evaluation Program Plan, System Evaluation Report for July 1, 1995 - December 31, 1995," Fernald Environmental Management Project, DOE, Fernald Area Office, Cincinnati, OH.

U.S. Environmental Protection Agency, 1988, "Guidance On Remedial Actions For Contaminated Groundwater At Superfund Sites," OSWER Directive No. 9283.1-2, Office of Solid Waste and Emergency Response.

U.S. Environmental Protection Agency, 1990, "ARARs Q's & A's: State Groundwater Antidegradation Issues," Publication 9234.2-11/FS, Office of Solid Waste and Emergency Response.

U.S. Environmental Protection Agency, 1992, "General Methods for Remedial Operation Performance Evaluations," EPA/600/T-92/002, Kerr Environmental Research Laboratory, Ada, OK.

U.S. Environmental Protection Agency, 1994, "Manual, Alternative Methods for Fluid Delivery and Recovery," EPA/625/R-94/003, Office of Research and Development, Washington, DC.

Weber, W. J. and T. C. Voice, 1983, "Adsorption of Humic Substances: the Effects of Heterogeneity and System Characteristics," vol. 75, p. 612, Congressional Information Service, Inc., U.S. Dept. of Energy, Washington, D.C.

Appendix A

APPENDIX A

MODELING APPROACH WITH K_d TRANSITION

A.1.0 PURPOSE

Mobility of uranium in the Great Miami Aquifer (GMA) is tied to the interplay of several physicochemical processes: precipitation, dissolution, adsorption, desorption, and ion exchange. Uranium may be removed from groundwater by precipitation, ion exchange, and adsorption, or returned to groundwater by dissolution, ion exchange, or desorption. The affinity for one process to occur over another will vary within the aquifer as groundwater composition, redox potential, particle composition, and particle surface area vary. Therefore, propagation of a uranium plume through an aquifer is a dynamic event where all these processes may occur simultaneously.

Commonly used fate and transport models are inherently simplistic when dealing with the spectrum of geochemical processes involved in the fate and transport of contaminants. The majority of fate and transport codes use the distribution coefficient (K_d) to account for the "retardation" of a contaminant as it travels with the groundwater. In a strict geochemical sense, the K_d establishes the equilibrium partitioning of a contaminant between the aquifer solid and groundwater for the special case of fast and reversible adsorption (i.e., a linear isotherm). However, this is not the conceptual model that fits the dynamic geochemical system outlined above, and assumptions must be made when applying the K_d concept to the fate and transport modeling of aquifer systems.

In the remainder of this appendix, each geochemical process is discussed and assumptions are formulated to tie these processes to the K_d value in the fate and transport model. The appendix is concluded by summarizing how the technical considerations and assumptions are implemented in the modeling procedures.

A.2.0 GEOCHEMICAL PROCESSES

Precipitation of a solute from groundwater requires that the activity product of ions in the precipitated phase exceed the solubility product for the phase (i.e., there is a thermodynamic affinity for the phase to form). Additionally, kinetics play a role in formation of the nucleation site and diffusion of ions to the nucleated phase. For the case of uranium in GMA groundwater, two secondary uranium phases have been identified in Fernald soil: meta autunite ($Ca(UO_2)_2(PO_4)_2 \bullet 4H_2O$) and soddyite ($(OU_2)_2SiO_4 \bullet 2H_2O$) (Buck et al. 1994). The extent of these uranium phases within the GMA has not been established, but their presence in Fernald soils indicates their ability to nucleate and precipitate under ambient conditions over the lifetime of the facility.

Dissolution of identified uranium phases by groundwater requires that the activity product of the ions comprising the precipitated phase is less than the solubility product of the phase. From a kinetic viewpoint, the surface area of the solid phase is the most important factor affecting the dissolution under ambient temperature and pressure. Additionally, uranium phases formed under ambient conditions are expected to have a greater affinity to dissolve in groundwater as compared to uranium oxides formed at high temperature (e.g., UO_2), as indicated by solubility studies conducted on contaminated Fernald soils (Lee et al. 1993).

Adsorption refers to two distinct processes: physical adsorption and chemisorption (Lasaga 1981). Physical adsorption results from the intermolecular or Van der Waal's forces acting between the particle surface and ion. This is the initial step in removing the ion from solution. Chemisorption involves the formation of chemical or ionic bonds between the surface atoms and the adsorbed species. Although physical adsorption occurs rapidly, chemisorption is slow and requires that the physically adsorbed specie "age" on the site to allow time for the bonding reaction to take place. Once chemisorption has occurred, additional energy is required to remove the specie from the solid. Therefore, adsorption/desorption reactions tend to become irreversible with time (i.e., only a fraction of what is initially adsorbed to the solid can be removed or extracted by desorption), which is in contrast to the fully reversible assumption invoked in fate and transport models by the use of K_d.

Ion exchange is physical adsorption that is accompanied by desorption of a different specie. The exchangeability of an adsorbed ion depends on how it is attached to the soil particle; that is, physical adsorption versus chemisorption. Species physically adsorbed to the soil particle surface are readily exchanged, while chemisorbed particles are more commonly exchanged only when they are on the corners or edges of particle fragments (Lasaga 1981).

A.3.0 REPRESENTATION OF GEOCHEMICAL PROCESSES IN FATE AND TRANSPORT MODELS

The state of the art in many areas of geochemical research is embryonic (EPA 1990). For example, activity coefficients of ions in strongly mixed electrolytes, the thermodynamic properties of clays, and the thermodynamics of adsorption have yet to be accurately determined. Thermodynamic data for many minerals and organic aqueous species are unavailable. Therefore, much preparatory research must be done before suitable simulations of geochemical processes can be conducted. Although, a substantial number of computer codes are available to evaluate the distribution of chemical species in solutions, computer codes that model mass transfer or mass transport with simultaneous chemical reactions are currently limited in availability and/or scope.

A.3.1 COMPLEX MODELS

Four general types of computer codes are used to model aqueous geochemistry: thermodynamic codes (e.g., SUPCRT and PHAS20), distribution-of species codes (e.g., SOLMNEQ), reaction-progress codes (EQ3/6, PHREEQE, PHREEQEP, and ECES), and combined transport codes. Among these four types of computer codes, only the combined transport codes can directly simulate groundwater remediation operations.

Combined transport codes model chemical transport by combining aqueous-geochemistry codes with physical-transport codes. Two major approaches have been used: integrated codes simultaneously solve all mass, momentum, and energy-transfer equations, including those in which chemical reactions participate, for each time step in the evolution of the system; two-step models first solve mass momentum and energy balances for each time step and then re-equilibrate the chemistry using a distribution-of-species code. The CHMTRN, THCC, and CHMTRNS developed in late 80s are examples of integrated transport models. CHMTRN includes dispersion/diffusion, advection, adsorption of ions and complexes, aqueous complex formation, and dissociation of water. THCC is a variant that simulates uranium transport with variable temperature and oxidation potential. The latest version, called CHMTRNS (Noorishad et al. 1987), can simulate in one dimension both homogeneous aqueous phase and heterogenous temperature-dependent reaction kinetics. It has been applied to a number of simple problems involving reversible and irreversible dissolution, and oxidation-reduction reactions. It has not been tested with complex multicomponent systems. DYNAMIX (Liu and Narashimhan 1989 and 1989b) is an example of two-step transport model. It combines the transport code TRUMP with distribution-of-species code PHREEQE. The most recent version handles the thermodynamics of hydrolysis aqueous complexation, redox reactions and precipitation-dissolution.

Due to their complexities, intensive input data requirements, and difficulties of field verifications, combined transport models which also simulate complex chemical reactions, such as CHMTRNS and

DYNAMIX, are still not widely used in typical contaminant fate and transport modeling projects. Capabilities and major deficiencies of these complex transport codes are summarized in a EPA report (EPA 1990). The sampling and analysis required to develop a site-specific complex transport model using these codes is prohibitive with respect to cost and schedule. Therefore, it is not considered feasible or cost-effective to apply these codes to the development of remedial alternatives at the FEMP.

A.3.2 SIMPLIFIED MODELS

As an alternative to the complex combined transport models discussed in the previous section, most of the commonly applied groundwater contaminant fate and transport models only incorporate simple partitioning equations (Travis 1981) in a two-step approach. Well-known examples of these types of models include MODFLOW/MT3D, MOC, FEMWATER/FEMWASTE, and SWIFT. The models first solve mass, momentum and energy balances for each time step and then re-equilibrate the chemistry using the simple partitioning equations. These simple partitioning equations usually include parameters such as K_d to quantify the combined results of all relevant geochemical processes. These simpler models are used to provide estimates of the representative or conservative geochemical conditions in the study area. They usually can not simulate the actual time-dependent geochemical processes.

In common fate and transport models, K_d is used in a generic sense to include all geochemical processes in the continuum of precipitation, dissolution, physical adsorption, chemisorption, desorption, and ion exchange; albeit many users of fate and transport models do not state this assumption explicitly. K_d in the SWIFT model employed for Operable Unit 5 RI/FS and Baseline Remedial Strategy Report is used in this generic sense, and the implications of this assumption are highlighted below.

From a purely geochemical perspective, K_d implies equilibrium partitioning of a contaminant between soil and groundwater, where at any time interval the amount of contaminant removed by adsorption is equal to the amount released by desorption (i.e., adsorption and desorption ratios are equal). However, the release of adsorbed ions is a function of time (Lasaga 1981), and as the resident time of the absorbed ion increases there is a greater probability that the ion will chemisorb to ions in the structure of the solid phase. Once chemisorption takes place, it takes a greater amount of energy to remove the chemisorbed ion from the solid (i.e., desorb), and there is some diminishing return on the removal of the adsorbed contaminant from the solid.

The chemisorption process may manifest itself in measured "apparent" K_d values presented for desorption batch tests reported in Attachment F.8.IV, Appendix F of the Operable Unit 5 FS Report (DOE 1995a). In these batch tests, the assumption was made that uranium in excess of background was adsorbed uranium, and an increase in the "apparent" K_d is an artifact of the removal of some portion of the contaminant from the adsorption/desorption process. To illustrate, consider a soil with adsorbed uranium of 2 mg/kg in equilibrium with groundwater having a uranium concentration of 1 mg/L, with the K_d being equal to 2 L/kg. The groundwater is removed from the soil during remediation and the next volume of groundwater equilibrates at a uranium concentration of 0.1 mg/L with soil having a uranium concentration of 1.8 mg/kg. The "apparent" K_d would be measured as 18 L/kg. However, if the true K_d remains at 2 (0.2 mg/kg $\div$ 0.1 gm/L), the implication is that 1.6 mg of uranium is chemisorbed on a kg of solid. Alternatively, the assumption that uranium in excess of background is adsorbed may be incorrect if chemisorbed or precipitated uranium is present. This situation in FEMP surface soil has been verified and evaluated in a laboratory multi-phase desorption batch test study in which 30 soil samples were analyzed (DOE 1995c).

A.4.0 SITE-SPECIFIC CONSIDERATIONS

The rate of uranium adsorption/desorption processes will control potential mobility of uranium as well as aqueous-phase concentrations in the GMA. Therefore, estimates of the groundwater cleanup time and the treatment requirements during groundwater remediation are highly dependent on modeling assumptions regarding the uranium adsorption/desorption processes. Because, the SWIFT model can only use one K_d value in a model simulation, the previous modeling approach (e.g., FS modeling [DOE 1995a]) used constant uranium K_d values throughout the duration of groundwater remediation. The uranium K_d value used in a specific model simulation either represented the adsorption or the desorption condition. However, as described in Attachment F.3.I, Appendix F of the Operable Unit 5 RI Report (DOE 1995b), adsorption and desorption processes are not fully reversible and may have significantly different "apparent" solid/liquid equilibrium ratios.

Due to the termination of source loading and removal of initial dissolved mass, it is expected that the geochemical conditions will change during groundwater remediation. The adsorption dominant process in the early stage of remediation will become a more desorption dominant process in the later stage. Because, even under the same groundwater flushing rate, the apparent releasing rate of residual mass during the desorption process is much slower than the original adsorption process, the uranium "apparent" K_d value is expected to increase during groundwater remediation. It is important to note that the instantaneous equilibrium assumption is still required for using the "apparent" K_d concept in a model during the desorption dominant process. Only the equilibrium ratio is changed in the transport model.

To handle the mass of chemisorbed or precipitation uranium on the aquifer solids, adjustments can be made to the mass balance calculation or "apparent" K_d value. A negative mass loading may be used to account for the uranium mass that is unavailable for desorption, or a larger "apparent" K_d value can be used to retain the uranium mass on the aquifer solids. For either case, additional uncertainty presents itself at the point selected to begin the negative loading or increase the "apparent" K_d, and this is addressed in Section A.4.6. As a matter of continuity with previous fate and transport work at Fernald, the "apparent" K_d value was changed from a lower adsorption value to a higher desorption value to account for uncertainty in the uranium mass retained by chemisorption or precipitation. The assumptions invoked for this analysis are that the higher "apparent" K_d value will:

- Account for chemisorbed or precipitated uranium that may persist for some time in the aquifer and
- Mimic the anticipated retention of some uranium by chemisorbed and precipitation forms after initial extraction of present groundwater.

Key technical considerations for the new modeling approach are described in this section. These considerations identify the factors and issues that need to be quantified or resolved in the modeling approach. In order to incorporate the transition of uranium K_d value into the modeling approach, several important factors need to be properly characterized.

A.4.1 "APPARENT" URANIUM K_d DURING ADSORPTION

A uranium K_d value of 1.78 L/kg is representative of the adsorption dominant conditions. This value was determined through the transport model calibration process which simulated the uranium loading (primarily through surface water infiltration) in the past 40 years (DOE 1993 and 1994) to match the current groundwater plume. During this period, a significant amount of uranium contaminated surface runoff infiltrated through Paddys Run and the SSOD into the Great Miami Aquifer. The resulting groundwater plume then migrated south and southeast from the losing sections of these two surface water bodies. Due to this continuous loading of uranium mass, the dominant process in the aquifer during the past 40 years was adsorption of uranium onto aquifer soil. During the early stage of groundwater remediation before the source loading is terminated and initial dissolved uranium is extracted, the dominant geochemical process will still be adsorption.

A.4.2 "APPARENT" URANIUM K_d DURING DESORPTION

During groundwater remediation, after the source loading is terminated and initial dissolved uranium is extracted, the dominant geochemical process will begin to shift to desorption. Residual uranium mass adsorbed on soil will start to dissolve when groundwater concentrations are significantly reduced by extraction. A uranium K_d value of 17.8 L/kg is considered representative of the desorption dominant conditions. As presented in Attachment F.8.IV, Appendix F of the Operable Unit 5 FS Report (DOE 1995a), this value was determined through regression analysis of results from desorption batch tests of contaminated aquifer soil samples.

The numerical difference between 1.78 and 17.8 L/kg may not seem to be significant considering uncertainty usually associated with inorganic K_d values. However, the amount of uranium currently in the GMA will be 10 times higher if an initial K_d value of 17.8 L/kg is used directly instead of the 1.78 L/kg value. The resultant uranium mass will significantly exceed all the independent estimates of mass that may be present in the aquifer (Boback et al. 1987). Therefore, from a mass-balance point of view the 1.78 and 17.8 L/kg K_d values are significantly different for determining the starting mass of uranium in the GMA and should present two very different geochemical conditions.

A.4.3 TIMING OF THE TRANSITION

In reality, the transition between adsorption and desorption conditions will be a gradual and continuous process. However, the SWIFT model cannot simulate a continuous transition process. In order to use the SWIFT model, it is necessary to simplify the continuous process into a two-stage process. The first stage will simulate the adsorption dominant period while the second stage simulates the desorption dominant period. Conceptually, a significant variation of the uranium geochemical condition may occur immediately after the source loading is terminated and the initial dissolved mass is extracted. Therefore, the "apparent" K_d transition can be assumed to happen right after both conditions (i.e., source termination and extraction of initial dissolved mass) are satisfied.

A.4.4 MASS BALANCE

The mass of uranium in the aquifer before and after transition of the K_d value should remain the same in the model. Only the distribution of overall mass between the aqueous and solid phases is changed at the time of K_d transition. Predicted groundwater concentrations and uranium adsorption K_d of 1.78 L/kg should be used to determine the overall mass at the time of transition. The "apparent" uranium desorption K_d value of 17.8 L/kg should then be used to redistribute the uranium mass between the two phases.

A.4.5 REMEDIATION SCHEDULE

Due to the soil remediation schedule and the need for sequential starts of groundwater extraction systems in different areas, transition of the "apparent" K_d value in different portions of the aquifer may occur at different times. Therefore, groundwater plumes in different areas may need to be simulated separately. In general, multiple model runs and superposition of results will be required to combine different timings of transitions among the recovery well systems. However, a consistent groundwater flow model that simulates the site-wide extraction/injection rate schedule needs to be used as the common basis for all the separate transport model runs. Only the targeted plumes and the uranium geochemical conditions will be varied among simulation runs for which the results are to be superimposed.

A.5.0 GENERAL MODELING PROCEDURES

Based on the previous discussions, an alternative modeling approach using the existing SWIFT model was developed and used to more realistically simulate the uranium adsorption/desorption process during groundwater remediation. A transition of the "apparent" uranium K_d value from an adsorption dominant condition to a desorption dominant condition during remediation was implemented in this approach. This section describes the approach as it was applied to select the new baseline groundwater remedial strategy.

Technical considerations described in the previous sections are implemented in the following modeling procedures:

Step 1 Specify the extraction/injection rate schedule and complete the flow model simulation
The site-wide groundwater flow conditions under the specified extraction/injection operation will not be affected by the modifications in the contaminant fate and transport simulations.

Step 2 Separate the initial overall groundwater plume into multiple plumes
Based on the local soil remediation schedule and the extraction/injection rate schedule, the transition of the geochemical condition may occur at different times for different portions of the overall plume.

Therefore, it is necessary to divide the overall groundwater plume into multiple plumes according to the remediation schedule. These plumes will then be modeled separately, as in Steps 3-7.

Step 3 Determine the time required to extract initially dissolved mass in each individual plume
The time-dependent hydraulic capture zone of the recovery well system operated in each individual plume needs to be determined using particle tracking in order to estimate the time required to extract the initially dissolved contaminant mass. Another approach is to run the fate and transport model to determine the local cleanup time assuming no adsorption/desorption (i.e., K_d = 0 L/kg) and no additional loading.

Step 4 Determine appropriate transition time of K_d for each individual plume
The one-step transition is assumed to happen right after the source termination and extraction of initial dissolved mass. Therefore, between the time required to complete source remediation and the time required to extract initially dissolved mass, select the longer time frame as the approximated transition time of geochemical conditions.

Step 5 Complete the Stage I fate and transport simulation for each subarea
Use a K_d value of 1.78 L/kg to simulate the adsorption dominant period (i.e., from the current time up to the transition time).

Step 6 Assign initial concentrations for Stage II in each subarea
Redistribute the total residual mass in each model block at the end of Stage I between the aqueous and solid phases using a K_d value of 17.8 L/kg.

Step 7 Complete the Stage II fate and transport simulation for each subarea
Use a K_d value of 17.8 L/kg to simulate the desorption dominant period (i.e., from the transition time until site-wide cleanup is achieved).

Step 8 Overlay the fate and transport modeling results of each subarea
Superimpose the subarea-specific modeling results obtained in Steps 5 and 7 at select time points throughout the groundwater remediation.

Step 9 Postprocess the final results
Time-specific site-wide groundwater plume contours, treatment capacity requirements, outfall concentrations, and other performance measures can be obtained from the combined groundwater concentrations.

A.6.0 UNCERTAINTY ANALYSIS

Modeling results need to be evaluated considering the uncertainties associated with the above important factors. Among the important factors, uncertainty regarding timing of "apparent" K_d transition is considered the highest because currently it is not based on any laboratory studies or model calibration. Therefore, model simulations with delayed transitions (i.e., assuming the "apparent" K_d transition will not occur immediately after the source termination and extraction of one additional pore volume) have been conducted to quantify the impact on the groundwater remediation time. A no-transition scenario (i.e., using a constant adsorption K_d value throughout the simulation as in the FS modeling) should provide an upper bounding estimate of the cleanup time estimate of a specific system design. On the other hand, a no-K_d scenario which assumes all the currently adsorbed mass will not dissolve during remediation should provide a lower bounding estimate of the cleanup time estimate. Therefore, three sensitivity runs (i.e., no-K_d, delayed-transition, and no-transition) in addition to the baseline approach (described in Section 5.0) were conducted to bracket the cleanup time for a given remedial system design.

Appendix F summarizes the model simulations conducted for the uncertainty analysis of the Baseline Remedial Strategy Report, and also reviews the previous sensitivity analyses conducted during the Operable Unit 5 RI/FS.

A.7.0 SUMMARY

Existing groundwater contaminant fate and transport modeling technologies still cannot efficiently simulate the dynamic, nonuniform, irreversible adsorption/desorption process in the real world. The modeling approach described in this appendix uses the existing SWIFT model, multiple intermediate model runs for subareas with different geochemical conditions, and superimposition of these results to allow a simulation of the transition of geochemical conditions. Therefore, a more realistic prediction of the groundwater remediation process can be achieved. Although this approach is still a simplification to a very complex adsorption/desorption process, the estimated scenario-specific treatment capacity requirement, treatment time, cleanup time, amount of uranium recovered, and impact to the Great Miami River are considered more accurate. Based on results from this modeling approach, the remedial strategy can be selected more appropriately.

A.7 REFERENCES

Boback, M.W., T.A. Dugan, D.A. Fleming, R.B. Grant, and R.W. Keys, 1987, "History of FMPC Radionuclide Discharges." Doc. No. FMPC-2082 (Revision to FMPC-2058). Westinghouse Materials Company of Ohio, Cincinnati, Ohio.

Buck, E.C., J.C. Cunnane, N.R. Brown, and N.L. Dietz, 1994, "Analytical Electron Microscopy Characterization of Uranium-Contaminated Soils from the Fernald Site," Argonne National Laboratory, Chemical Technology Division, FY 1993 Report, ANL-94/38, Argonne, Illinois.

Lasaga, A.C., 1981, Rate Laws of Chemical Reactions, in Reviews in Mineralogy, Volume 8, Kinetics of Geochemical Processes, A.C. Lasaga and R.J. Kirkpatrick, eds., Mineralogical Society of America, Washington, D.C.

Lee, S.Y., M. Elless, and F. Hoffman, 1993, "Solubility Measurement of Uranium in Uranium Contaminated Soils," ORNL/TM-12401, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Liu, C.W. and T.N. Narashimhan. 1989a. Redox-Driven Multiple Species Reactive Chemical Transport in Groundwater Systems, Part 1: Model Development. Submitted to Water Resources Research 25:869-882.

Liu, C.W. and T.N. Narashimhan. 1989b. Redox-Driven Multiple Species Reactive Chemical Transport in Groundwater Systems, Part 2: Verification and Application. Submitted to Water Resources Research 25:883-910.

Noorishad, J., C.L. Carnahan, and L.V. Benson. 1987. A Report on the Development of the Non-Equilibrium Reactive Chemical Transport Code CHMTRNS. Lawrence Berkeley Laboratory Report, LBL-22361, 229 pp.

Travis, C. C. and E. L. Etnier, 1981, "A Survey of Sorption Relationships for Reactive Solutes in Soil," J. Environ. Qual., Vol. 10, no. 1.

U.S. Department of Energy, 1993, "Groundwater Modeling Report - Summary of Model Development," Fernald Environmental Management Project, DOE, Fernald Field Office, Cincinnati, OH.

U.S. Department of Energy, 1994, "SWIFT Great Miami Aquifer Model - Summary of Improvements Report," Fernald Environmental Management Project, DOE, Fernald Field Office, Cincinnati, OH.

U.S. Department of Energy, 1995a, "Feasibility Study Report for Operable Unit 5," Final, Fernald Environmental Management Project, DOE, Fernald Area Office, Cincinnati, OH.

U.S. Department of Energy, 1995b, "Remedial Investigation Report for Operable Unit 5," Final, Fernald Environmental Management Project, DOE, Fernald Area Office, Cincinnati, OH.

U.S. Department of Energy, 1995c, "Operable Unit 5 K_1 Sampling And Analysis Results," Final, Fernald Environmental Management Project, DOE, Fernald Area Office, Cincinnati, OH.

U.S. Environmental Protection Agency, 1990, "Assessing the Geochemical Fate of Deep-Well-Injected Hazardous Waste: Summaries of Recent Research," EPA/625/6-89/025b, Office of Research and Development, Washington, DC, July 1990.

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Appendix B

APPENDIX B

FEASIBILITY OF USING HORIZONTAL WELLS FOR GROUNDWATER REMEDIATION

B.1.0 INTRODUCTION

The feasibility of using horizontal wells for groundwater remediation at the FEMP was evaluated as a part of the process to finalize the groundwater strategy for remedial design purposes. Literature reviews, vendors' recommendations, and results of model simulations was gathered for determining the feasibility and relative cost of applying horizontal wells to groundwater remediation. Appendix B briefly presents the process and important findings of this feasibility evaluation task.

B.2.0 OVERVIEW

Specific objectives, general procedures, and deliverables of this evaluation are listed in the following sections.

B.2.1 OBJECTIVES

The following objectives were first identified:

- Evaluate the feasibility of using horizontal recovery wells for groundwater remediation at the FEMP
- Determine cost and benefits
- Incorporate the collected information into the selection process for the new baseline groundwater remedial strategy.

As indicated by these objectives, the two key questions to be answered by this task are about the feasibility and cost effectiveness of horizontal wells.

B.2.2 EVALUATION PROCEDURES

A series of evaluation procedures were followed in order to cover all the important sources of information regarding the feasibility, cost, and performance of horizontal wells. Both qualitative and quantitative evaluations were conducted based on relevant general and site-specific conditions. The evaluation procedures can be summarized by the following:

- Identify potential installation techniques
  - Directional drilling (blind well and continuous well)
  - Vertical caisson with radial collector wells (Ranney well)
- Select target areas at the FEMP for applying horizontal wells
- Review area-specific hydrogeological and contamination data
- Conduct literature search
- Identify and consult internal and external experts
- Estimate achievable inflow distributions and optimal well layouts by modeling
- Compare the available and normally applied installation techniques
  - List major well-design considerations
  - Identify potential risks and logistical problems during installation
  - Determine the most effective design and installation approach
- Define the maintenance requirements
- Estimate the relative cost of horizontal wells versus vertical wells.

B.2.3 DELIVERABLES

Specific deliverables of this evaluation included:

- Summary of the feasibility
- Conceptual presentation of the most effective horizontal well design
- Cost information.

After completion of this task, information presented in these deliverables was then incorporated in the development of a potential groundwater remediation scenario using horizontal wells. This potential scenario was evaluated during the selection process of the new baseline remedial strategy.

B.3.0 IMPORTANT FINDINGS

Important findings of this evaluation task, which will directly impact the remedial strategy selection at the FEMP, are described in this section. Other more general descriptions regarding horizontal well design, installation, and application can be found in an EPA manual (EPA 1994).

B.3.1 PATTERNS OF THE INFLOW DISTRIBUTIONS

Due to the long screen length, a uniform or a transmissivity-weighted inflow pattern usually assumed for a relatively shorter vertical well screen is not appropriate for a horizontal extraction well. Therefore, a pipe flow model (i.e., Fathom) was first used to determine the inflow rate distributions along various horizontal well-screen designs. The Fathom model (AFT 1995) uses Newton-Raphson method to solve the fundamental pipe flow equations that govern mass and momentum balance. Numerical solutions are obtained by iteration, and matrix methods optimized for computational speed are employed in Fathom to obtain numerical convergence. Fathom also combines the traditional piping network modeling with easy-to-use graphical user interface with drag-and-drop capability. Factors considered in this analysis included well diameter, length, depth, number of pumps, and the aquifer's response to pumping.

In this pipe model the aquifer was simulated as a series of reservoirs 25 feet (i.e., a typical vertical well-screen length) apart along the pipe with constant water elevation equal to the average water table elevation before pumping. Elevation of the horizontal pipe is set at about 20 feet below the water table. The aquifer step drawdown test results (i.e., the pumping rate versus the drawdown curve) were then embedded in a series of conceptual energy-loss components between each reservoir and the horizontal pipe. Therefore, when a specific inflow occurred between a conceptual reservoir and the horizonal pipe, the component linking the reservoir to the pipe caused a head loss equivalent to the drawdown due to pumping at the same rate. In order to approximate the accumulated drawdown due to adjacent inflows, the drawdown curve was increased by a factor of two, except for the two reservoirs at each end of the well-screen. Various pumping rates from one end or both ends of the pipe were then simulated. The simulated inflow rates within each of the four quarter sections of the horizontal pipe were then calculated. Finally, the four sectional inflow rates were then converted into percents of the total inflow (i.e., normalized against the total flow).

The following three types of horizontal well-screen designs were simulated using the pipe model:

- Type A - Blind well with a fixed diameter
- Type B - Blind well with variable (i.e., telescoped) diameters
- Type C - Continuous well (i.e., pumps at the both ends) with a fixed diameter.

The estimated sectional inflow rate distribution along the length of the above three well-screen designs are summarized below:

- Type A - 55, 20, 10, and 15 percent (starting from the pumping end)
- Type B - 40, 25, 20, and 15 percent (starting from the pumping end)
- Type C - 30, 20, 20, and 30 percent (pumping from both ends).

B.3.2 OPTIMAL LAYOUT OF HORIZONTAL WELLS

After the potential inflow rate distribution patterns were determined, SWIFT model simulations were conducted to predict uranium transport using various horizontal well layouts (i.e., specific types, lengths, locations, orientations, and extraction rates) for groundwater remediation. The specific extraction rate of a horizontal well was simulated by assigning extraction rates in multiple model grid blocks where the horizontal well is located. The estimated inflow distribution pattern for the type of well simulated was used to determine these extraction rates.

Figure B-1 shows the most effective horizontal well layout evaluated for the South Field/SSOD and South Plume areas. Five horizontal wells were used in this scenario including:

- Two Type C horizontal wells with 500-foot screens and pumping at 500 gpm each (a total of 1000 gpm) in the South Field
- One Type B horizontal well between the SSOD and Willey Road with a 500-foot screen and pumping at 400 gpm
- One Type B horizontal well with a 500-foot variable diameter screen pumping at 900 gpm
- One Type B horizontal well with a 375-foot variable diameter screen pumping at 300 gpm.

Geological cross sections along each of these five well axes were prepared and evaluated to verify that the well type specified can be installed. Type B horizontal wells were used along the fence line primarily to avoid the need for off-property surface access. Although not specifically simulated, it was assumed that two Type C horizontal wells and one Type B well can also be used in the waste pit and Plant 6 areas, respectively. In a horizontal well remediation scenario, these three horizontal wells can be used to replace all the vertical extraction wells specified in the remedial strategy presented in the Operable Unit 5 FS Report (DOE 1995) for these two areas.

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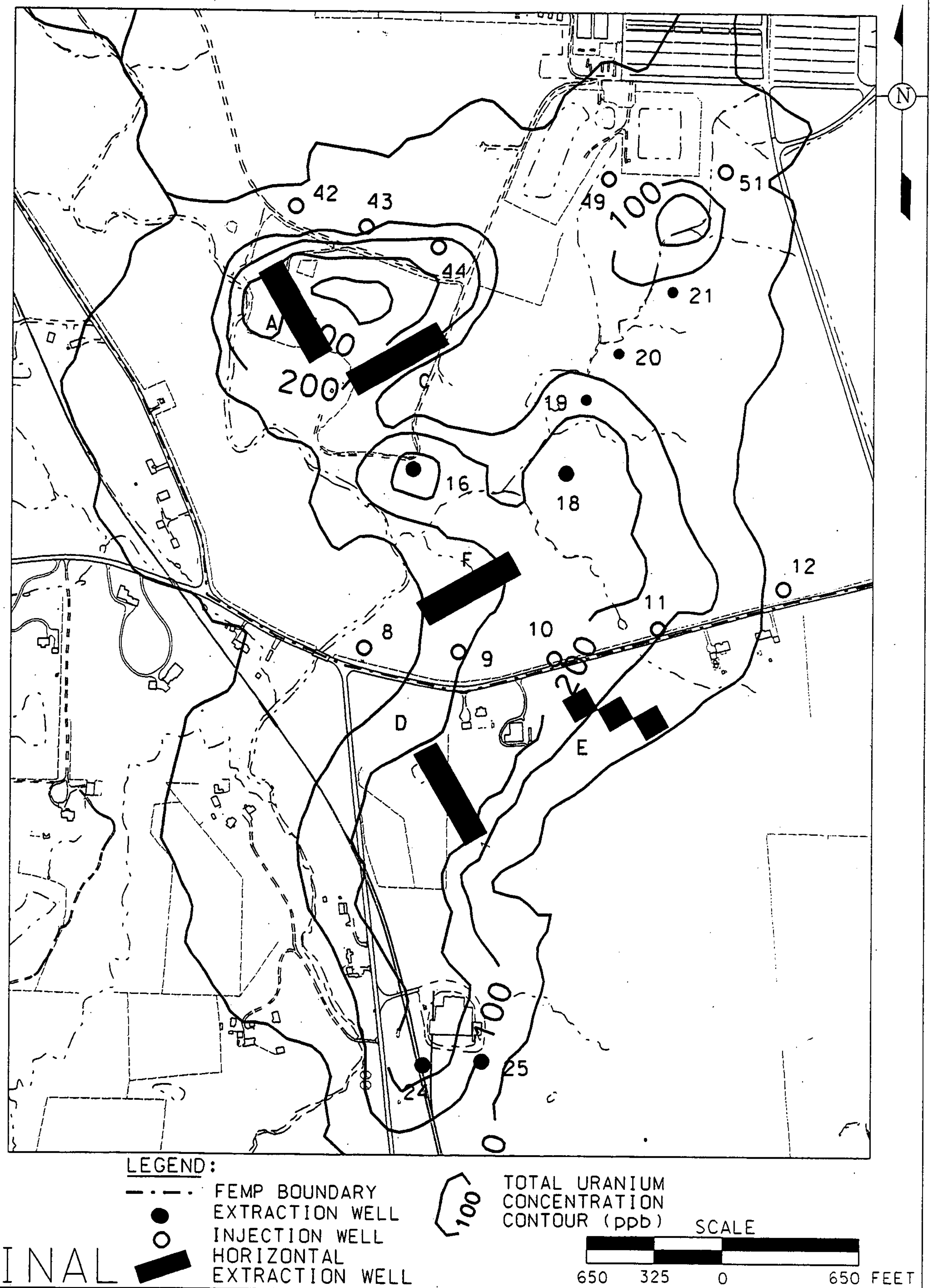

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FIGURE B-1. HORIZONTAL WELL LAYOUT EVALUATED FOR THE SOUTH FIELD/SSOD AND SOUTH PLUME AREAS

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B.3.3 WELL INSTALLATION

Because a horizontal well can be installed by either horizontal directional drilling or Ranney technology, the advantages and disadvantages of these two approaches were evaluated to select the appropriate installation method in the optimal layout determined through model simulations. Other major design considerations regarding the horizontal wellbore specifications include: trajectory, diameter, casing/screen materials and filter pack.

The major advantages of using horizontal directional drilling include the capability to install much longer wells (i.e., with a more than 350-foot long horizontal section) and continuous wells (i.e., wells with both ends open to the ground surface). The expected cost of directional drilling is also lower than the Ranney approach. However, in order to facilitate the desired high pumping capacity (i.e., 300 to 900 gpm), well diameters that are larger than is typically done in directional drilling applications will need to be installed. Another potential problem associated with the directional drilling is that it is often difficult to properly redevelop the well-screen area to remove fine materials and residual drilling mud used during the drilling process from the formation. Even with adequate well-screen diameters, there is no assurance that effective well-maintenance cleaning can be performed if needed, due to the curvature of the well precluding the use of appropriate cleaning devices.

Ranney wells have a better chance to obtain the high pumping capacities because no drilling mud is required during installation and larger or multiple pumps can be installed in the 9- to 16-foot caisson. Ranney wells can also have multiple lateral drains in a single caisson. In a Ranney well, access to the well-screens is easily made in the caisson so that proper well-cleaning equipment can be used to rehabilitate the well-screens, if required. However, a significant amount of soil needs to be excavated and disposed of during installation and the required length of the horizontal well is much longer (i.e., up to 350 feet) than is typically done in Ranney well applications. Installation of the large caisson and associated health and safety requirements will result in much higher costs for Ranney wells than wells installed by directional drilling.

Based on the advantages, disadvantages and limitations of the two installation technologies, a suitable technology was selected for each horizontal well. Directional drilling was selected for installing the five continuous horizontal wells (i.e., pumped from both ends) in the South Field, waste pit, and

Plant 6 areas because contaminated soil in these areas which will preclude the Ranney approach. Additional horizontal wells can be installed in these areas to ensure the desired overall extraction rates, if deemed necessary by the potentially lower achievable pumping rate in each well. Stainless steel casing and prepacked screens are preferred for these wells. The Ranney approach was selected for installing the three horizontal wells in the South Plume area because the overburden is considered clean and higher pumping rates are required. Although these selections do not affect the estimated performance measures, they will be reflected in the cost estimates.

B.3.4 RISKS AND RELATIVE COST

Installation

The typical cost of a horizontal well installation using directional drilling technology is about 5 to 10 times higher than a vertical well. Following are some of the reasons for the higher installation cost for a horizontal well:

- Mobilization of special equipment
- Larger amount of contaminated cuttings
- Need for an effective guidance system
- Longer casing and screen
- Difficulty of filter pack installation
- Decontamination of special equipment (e.g., rig, guidance system and mud system).

The installation cost of a Ranney well will be higher than a directionally drilled horizontal well due to the following factors:

- Very few contractors have Ranney well experience or capability
- Need for a large reinforced concrete caisson
- Additional soil excavation and disposal
- Health and safety requirements for the deep and confined working space.

A major cost component of horizontal well installation will be for covering the risk of potential failure during installation and the subsequent need for rework. Contractors usually use larger safety factors (sometimes adding up to 200 percent to the real cost of the horizontal well installation) when bidding on horizontal well installation projects. Potential problems during horizontal well installation at the FEMP may include:

- Access to a large laydown and entrance area
- Difficulty of steering the drilling bit in unconsolidated sand and gravel

- Higher risk of wellbore collapsing in unconsolidated sand and gravel
- Side effects of the drilling fluid
- Unexpected hard materials such as rock or concrete debris along the designed path
- Potential difficulties during well completion and development.

Currently some experts in the horizontal directional drilling industry are promoting a well design and installation technique for horizontal wells that is standardized, low risk, and familiar to the contractors. Details of these proposed approaches are described in a recent paper (Wilson 1996).

Operation and Maintenance

Cost savings from using horizontal wells will be realized primarily during operation from the following factors:

- Smaller number of pumps
- Less complex piping network and operational procedure
- Shorter cleanup and treatment time frame.

There are several concerns during operation of the horizontal wells:

- Need for a higher groundwater treatment capacity
- Questionable long-term performance of pumps in inclined or horizontal positions
- Curvature of the well may preclude use of appropriate well-cleaning devices
- Difficulty targeting specific smaller zone of residual contamination along the well screen.

Relative Cost

Estimated ranges of the relative costs of horizontal well installations when compared to a typical vertical extraction well are listed below:

Types of Wells	Relative Costs
One on-property vertical extraction well	1
One horizontal extraction well	4.5 - 6
One Ranney well	7.5 - 10
One additional horizonal section from a Ranney well	4 - 6

The fully burdened cost (i.e., well design/installation/development, pump and piping) of a vertical extraction well at the FEMP is about $500,000. The above-listed relative costs also include the piping and pump associated with the well.

B.4.0 CONCLUSION

The general conclusion of this investigation is that horizontal well technologies can be successfully applied at the FEMP as long as appropriate design, installation, and maintenance procedures are employed. However, the higher up-front capital costs of horizontal wells need to be justified by significantly shorter groundwater cleanup and treatment times when compared with vertical wells. Improvements of installation technologies which may reduce cost and risk associated with environmental horizontal well installation are continuously being developed by the industry. Progress in the industry and on-going application projects should be closely followed if horizonal well technologies are selected to be used at the FEMP.

It is important to highlight that horizontal wells have been discussed with the affected off-property landowner who has expressed concern that it is not reasonable to employ horizontal wells anywhere near residential dwellings.

REFERENCES

AFT, 1995, "AFT Fathom™ User's Guide, AFT Fathom version 2.0, Pipe Flow Analysis System for Windows™," Applied Flow Technology, Louisville, OH.

U.S. Department of Energy, 1995, "Feasibility Study Report for Operable Unit 5," Final, Fernald Environmental Management Project, DOE, Fernald Area Office, Cincinnati, OH.

U.S. Environmental Protection Agency, 1994, "Manual, Alternative Methods for Fluid Delivery and Recovery," EPA/625/R-94/003, Office of Research and Development, Washington, DC.

Wilson, David D., 1996, "Use of Horizontal Drilling in Environmental Remediation: A Horizontal Well Case Study," presented in a horizontal well course, Albuquerque, NM, January 1996.

Appendix C

APPENDIX C

RESULTS OF OVERALL RELATIVE COST COMPARISONS

TABLE C-1

SUMMARY OF THE SITE-SPECIFIC PROJECT EXPERIENCES FOR ESTIMATING RELATIVE UNIT COSTS OF MAJOR COMPONENTS

Summary
On-property vertical extraction well (including pump and piping): Installation of the nine Phase I South Field extraction wells. Considered to have low uncertainty.
Off-property vertical extraction well (including condemnation, pump and piping): Installation of the five South Plume recovery wells. Considered to have moderate uncertainty.
Vertical injection well: Installation of the nine Phase I South Field extraction wells without the pump (based on preliminary conceptual design injection operation will not require pumps). Considered to have low uncertainty.
Horizontal extraction well (by directional drilling, including pump and piping): No site-specific experience. Will be based on literature information. Considered to have high uncertainty.
Ranney well (including pump and piping): No site-specific experience. Will be based on literature and vendor information. Considered to have high uncertainty.
Additional horizontal section from a Ranney well (including pump and piping) No site-specific experience. Will be based on literature and vendor information. Considered to have high uncertainty.
O&M per vertical extraction well per year: Three years of operational data collected from the South Plume Recovery Well System. Considered to have low uncertainty in the first 10 years and moderate uncertainty thereafter.
O&M per horizontal extraction well per year: No site-specific experience. Will be based on vender information. Considered to have high uncertainty.
O&M per injection well per year: No site-specific experience. Will be based on vender information. Considered to have high uncertainty.
Expansion of groundwater treatment capacity to 2000 gpm: Installation of the AWWT and SPIT Systems. Considered to have low uncertainty.
250-gpm mobile groundwater treatment module: Installation of the IAWWT System. Considered to have low uncertainty.
Groundwater treatment per year: Over 2 years of operational data from the SPIT System. Considered to have moderate uncertainty in the first 10 years and high uncertainty thereafter.
General groundwater monitoring and reporting per year: Over a decade of groundwater sampling at the FEMP. Considered to have low uncertainty in the first 10 years and moderate uncertainty thereafter.

Notes: Low uncertainty - 10% or less
Moderate uncertainty - 10% to 30%
High uncertainty - 30% or more

TABLE C-2

SCENARIO-SPECIFIC RELATIVE CAPITAL COSTS

Components	Relative Unit Cost	25-Year Case		15-Year Case		10-Year Case		7.5-Year Case	
		Units	Cost	Units	Cost	Units	Cost	Units	Cost
Well/Pump/Piping									
On-Property Vertical Extraction Well	1	17	17	25	25	30	30	5	5
Off-Property Vertical Extraction Well	2	4	8	4	8	4	8	0	0
Vertical Injection Well	0.75	10	7.5	10	7.5	10	7.5	10	7.5
Directionally Drilled Horizontal Extraction Well	4.5 - 6[a]	0	0	0	0	0	0	5	22.5/30
Ranney Well	7.5 - 10[a]	0	0	0	0	0	0	1	7.5/10
Additional Horizontal Section from a Ranney Well	4 - 6[a]	0	0	0	0	0	0	2	8/12
Subtotal			32.5		40.5		45.5		50.5/64.5
Groundwater Treatment									
Expansion of Groundwater Treatment Capacity to 2000 gpm	7.5	1	7.5	1	7.5	1	7.5	1	7.5
250 gpm Mobile Groundwater Treatment Module	3	2	6	0	0	0	0	4	12
Subtotal			13.5		7.5		7.5		19.5
Total Capital Cost			46		48		53		70/84

[a]Estimated range of relative unit cost.

TABLE C-3

SCENARIO-SPECIFIC RELATIVE OPERATION AND MAINTENANCE COSTS

Tasks	Relative Unit Cost	25-Year Case		15-Year Case		10-Year Case		7.5-Year Case	
		Units	Cost	Units	Cost	Units	Cost	Units	Cost
Well O&M in the First 10 Years									
Per Vert. Extraction Well Per Year	0.07	152	10.64	164	11.48	179	12.53	49.5	3.46
Per Hori. Extraction Well Per Year	0.14							28	3.92
Per Injection Well Per Year	0.035	80	2.8	64	2.24	64	2.24	55	1.93
Subtotal			13.44		13.72		14.77		9.31
Well O&M after the First 10 Years									
Per Extraction Well Per Year	0.1	100	10.0	20	2.0	0	0	0	0
Per Injection Well Per Year	0.05	40	2.0	20	1.0	0	0	0	0
Subtotal			12.0		3.0		0		0
Groundwater Treatment O&M									
Per Year In The First 10 Years	6	10	60	10	60	9	54	7.5	45
Per Year After The First 10 Years	8	10	80	0	0	0	0	0	0
Subtotal			140		60		54		45
Monitoring/Reporting									
Per Year In The First 10 Years	2	10	20	10	20	10	20	7.5	15
Per Year After The First 10 Years	3	15	45	5	15	0	0	0	0
Subtotal			65		35		20		15
Total O&M Cost			230.44		111.72		88.77		66.97

TABLE C-4

SUMMARY OF THE ESTIMATED RELATIVE OVERALL GROUNDWATER REMEDIATION COSTS

Cost Components	25-Year Scenario	15-Year Scenario	10-Year Scenario	7.5-Year Scenario
Capital				
Well/Pump/Piping	32.5	40.5	45.5	50.5 - 64.5
Treatment	13.5	7.5	7.5	19.5
Well O&M	25.44	16.72	14.77	9.32
Treatment O&M	140	60	54	45
Monitoring/Reporting	65	35	20	15
Total	276.44	159.72	141.77	139.32 - 153.32

TABLE C-5

SUMMARY OF THE ESTIMATED RELATIVE OVERALL GROUNDWATER REMEDIATION COSTS
(Present Worth Costs In Millions At A Discount Rate Of 2.8%)

Cost Components	25-Year Scenario	15-Year Scenario	10-Year Scenario	7.5-Year Scenario
Capital				
Well/Pump/Piping	14.9	18.0	20.0	23.9 - 30.5
Treatment	6.8	3.8	3.8	9.8
Well O&M	9.7	6.9	6.3	4.2
Treatment O&M	53.5	26.6	24.2	20.6
Monitoring/Reporting	23.0	14.3	8.9	6.9
Total	107.9	69.6	63.2	65.4 - 72.0

TABLE C-6

SUMMARY OF THE ESTIMATED RELATIVE OVERALL GROUNDWATER REMEDIATION COSTS (Present Worth Costs In Millions At A Discount Rate Of 5.0%)

Cost Components	25-Year Scenario	15-Year Scenario	10-Year Scenario	7.5-Year Scenario
Capital				
Well/Pump/Piping	14.0	16.4	18.2	22.9 - 29.3
Treatment	6.8	3.8	3.8	9.8
Well O&M	8.0	6.0	5.5	3.9
Treatment O&M	44.2	24.3	22.4	19.3
Monitoring/Reporting	18.1	12.3	8.1	6.4
Total	91.1	62.8	58.0	62.3 - 68.7

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TABLE C-7

SUMMARY OF THE ESTIMATED RELATIVE OVERALL GROUNDWATER REMEDIATION COSTS
(Present Worth Costs In Millions)

Discount Rate	25-Year Scenario	15-Year Scenario	10-Year Scenario	7.5-Year Scenario
0.0 %	140	80	70	70 - 75
2.8 %	110	70	65	65 - 72
5.0 %	90	65	60	62 - 70

Appendix D

APPENDIX D

FEMP WASTEWATER TREATMENT SYSTEM DESCRIPTIONS

D.1.0 INTRODUCTION

D.1.0 INTRODUCTION

During the FEMP remediation, the wastewater treatment systems will include the AWWT system - Phases I and II, the IAWWT system, the SPIT, and the currently planned AWWT expansion. The effluents from these systems along with Sewage Treatment Plant effluent, uncontaminated wastewater (e.g., boiler plant blowdown), and bypassed (untreated) groundwater will combine at Manhole 176B to form the FEMP site's regulated discharge of uranium to the Great Miami River.

D.2.0 DESCRIPTION OF THE MAJOR TREATMENT SYSTEMS

Figure D-1 shows the treatment modules and simplified general wastewater flows in the overall FEMP centralized wastewater treatment system during remediation. The following sections describe the capacity, sources of wastewater, effluent quality, and current status of each of the existing and planned wastewater treatment systems.

D.2.1 AWWT - PHASE I

This system is intended to be used primarily for the treatment of uranium-contaminated storm water runoff from the former production area; however, when no storm water is available this system will be used to treat the less contaminated groundwater from aquifer remediation efforts. This system was designed as a 700-gpm throughput system; and the treatment capacity of this system is anticipated to be approximately 600 gpm on an annual average basis taking into account downtime for scheduled maintenance activities.

It is estimated that approximately 50 percent of system capacity will be dedicated to treatment of storm water and 50 percent to treatment of groundwater (i.e., 300 gpm each on an estimated annual average flow rate). At the present time, this system is only capable of a sustained throughput of approximately 400 gpm. Replacement of the existing tubular filtration system with multimedia filtration in the Spring of 1997 is anticipated to allow this system to achieve the nominal 600-gpm flow.

As mentioned above, the sources to this system are contaminated storm water runoff and extracted groundwater. The storm water discharges to the SWRB contain approximately 500 ppb uranium while the combined South Plume groundwater wells currently being pumped averages somewhat less than 20 ppb. This differential in concentration illustrates the need for a treatment philosophy of preferentially treating storm water over groundwater. However, if future groundwater remediation concentrations exceed that of storm water runoff, the priority would be reversed.

Based on initial system operational experience, it is estimated that this treatment system will be capable of maintaining a system effluent at approximately 20 ppb of uranium for storm water and lower for groundwater. Since it is projected that the treatment split between storm water and groundwater will be 50% storm water and 50% groundwater, it is anticipated that the annual average effective concentration will be approximately 10 ppb.

It should be noted that during periods of exceptionally high rainfall, the AWWT Phase I may not be able to keep up with the inflow to the SWRB. Therefore, in order to prevent an overflow of storm water to Paddys Run, storm water will be by-passed directly to the Great Miami River. This emergency bypass will be regulated under the Operable Unit 5 ROD commitments.

D.2.2 AWWT - PHASE II

This system is intended to treat the existing FEMP process wastewater and future remediation wastewater flows. The existing flows include all wastewater requiring uranium removal that are currently directed to the BSL, including waste pit area storm water runoff and contaminated General Sump flows. Future remediation flows, exclusive of the extracted groundwater, are intended to be directed to the BSL in order to take advantage of the lagoon's 8-million-gallon flow and concentration equalization capability. This system is used for backwashes of both the Phase I and Phase II systems and proposed to receive backwash from the AWWT expansion.

The Phase II system will be used for the treatment of remediation flows. However, in periods of low flow, extracted groundwater can be directed to this system for treatment. Treatment projections do not assume any groundwater treatment by the Phase II system.

Current flows from the BSL have a uranium concentration of approximately 2000 ppb and it is assumed that future additions of remediation wastewater will not alter this concentration significantly.

Based on initial system operational experience, it is estimated that the AWWT - Phase II system will be capable of maintaining a system effluent of approximately 20 ppb of uranium.

D.2.3 SPIT

The SPIT system is a 200-gpm treatment system dedicated to treatment of extracted groundwater only.

The SPIT system will continue to be dedicated to treatment of extracted groundwater at an average throughput of 150 gpm and has shown that an effluent concentration of 5 ppb of uranium can be expected.

D.2.4 IAWWT

This treatment system was designed as a 300-gpm treatment system to treat uranium contaminated storm water before the installation of the AWWT - Phase I system. Current plans are to dedicate this system for groundwater treatment. The annual average throughput flow rate is expected to be 350 gpm when dedicated to treatment of groundwater. Based on the SPIT operational experience, this system should be able to achieve an effluent uranium concentration of 5 ppb when totally dedicated to groundwater treatment.

D.2.5 AWWT SYSTEM EXPANSION

This treatment system is currently in the construction phase. The treatment system will be dedicated to extracted groundwater at a design capacity of 1800 gpm. It is anticipated that this treatment system will be able to process approximately 1500 gpm on an annual average basis. This planned reduction from full capacity takes into account downtimes for scheduled maintenance and unplanned interruptions of flow. As this new system is very similar in design to the SPIT system, it is expected to perform similarly. Therefore, an effluent uranium concentration of 5 ppb can be expected.

D.3.0 PROJECTED GROUNDWATER TREATMENT CAPACITY

The bulk of the dedicated groundwater treatment capacity will come from the AWWT system expansion with its anticipated throughput of 1500 gpm. Fifty percent of the anticipated average capacity of the AWWT - Phase I capacity of 600 gpm (i.e., 300 gpm) will be dedicated to groundwater treatment. The IAWWT units will provide 250 gpm of dedicated groundwater treatment capacity annually. The SPIT system is predicted to provide an average of 150 gpm for groundwater treatment.

Based on the current progress of the design and construction processes, the projected operational schedule of the combined groundwater treatment capacity is summarized in Figure D-2. A conservatively estimated effective groundwater treatment capacity of 2000 gpm with an effluent uranium concentration of 5 ppb, available by January 1998, will be incorporated as a part of the baseline groundwater remediation strategy.

D.4.0 OPERATION AND MAINTENANCE STRATEGY

A master Operations and Maintenance Plan (O&MP, defined as Task 2 in the Operable Unit 5 Remedial Design Work Plan [DOE 1996]) will be developed to guide and coordinate the extraction, collection, conveyance, treatment, and discharge of all groundwater, storm water, and remediation wastewater generated site-wide over the life of the FEMP's cleanup mission. The plan will delineate the commitments, performance goals, operating schedule, direct discharge and treated water flow rates, system-by-system sequencing, and other operating constraints and priority required to balance site-wide water management needs so that compliance with the FEMP's discharge limits is maintained. The plan will serve to inform FEMP management and supervision, DOE, and the regulatory agencies of the planned operational approaches and strategies that are intended to meet the regulatory agreements made during the Operable Unit 5 RI/FS process. The plan will also serve as the focal point for coordinating and scheduling remedial wastewater conveyance and treatment needs with other site projects throughout the duration of the FEMP's cleanup mission.

Specifically, the plan will address the following:

- Definition and prioritization of the flow routing decisions associated with aquifer restoration and site-wide wastewater treatment
- Operating philosophy for groundwater extraction and injection well systems, other remediation wastewater collection systems, and groundwater and wastewater treatment systems
- System and component maintenance requirements
- FEMP operating organization and protocols
- Notifications and reporting.

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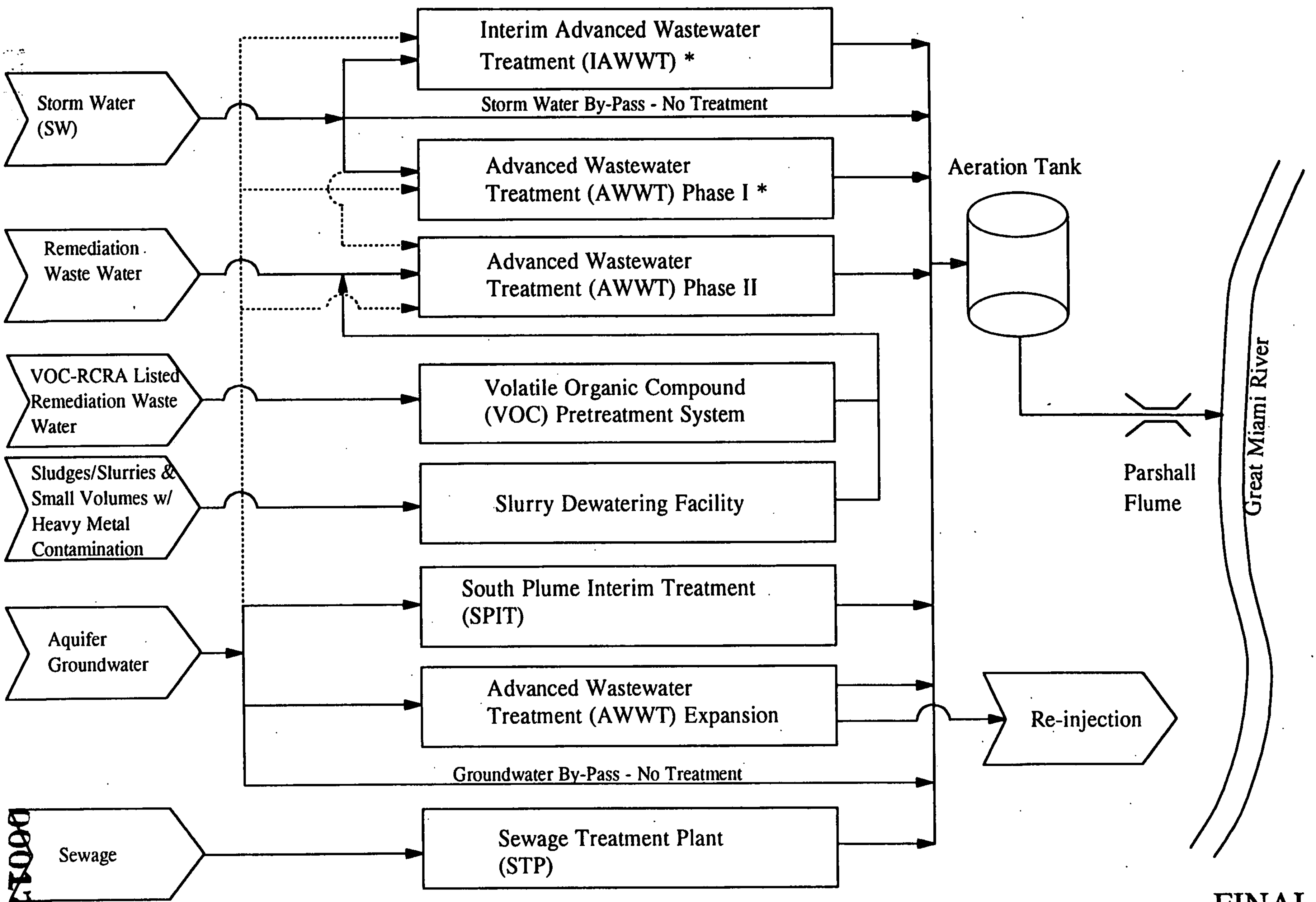
This plan is not intended to provide specific operating instructions to operations or maintenance personnel; however, it is to be used as a reference and site policy to ensure that planned modes of operation are consistent with regulatory requirements and FEMP commitments. Therefore, this plan will also provide the FEMP operating and maintenance organizations with the basis for development of more detailed documents (e.g., Standard Operating Procedures and Standing Orders). These existing documents will be updated (revised, combined, or eliminated) to reflect the general strategies and guidelines defined in this O&MP.

All environmental monitoring activities conducted in support of operations and maintenance decisions will be conducted and reported through the Integrated Environmental Monitoring Plan (Task 9 in the Operable Unit 5 Remedial Design Work Plan [DOE 1996]). The O&MP will be modified as necessary over the life of the remedy to accommodate expansions to the system or the retiring of individual restoration modules from service once area-specific cleanup levels are achieved. The plan will also be amended as needed to address future agreements with the regulatory agencies or to reflect the experience gained from actual operations. These amendments will be formally issued on an annual basis and the plan will be revised and re-issued every 2 years. The O&MP will thus serve as a living guidance document to guide operations staff in implementing required adjustments to the system over time.

The first edition of the O&MP will cover specific components of the existing FEMP groundwater recovery well system, storm water management, and wastewater treatment system as of Spring 1997. Future additions or expansions of these systems as currently defined in the Operable Unit 5 Remedial Work Plan (DOE 1996) and this Baseline Remedial Strategy Report will also be listed for general scheduling purposes. The O&MP is scheduled to be submitted to the regulatory agencies in July 1997.

REFERENCES

U.S. Dept. of Energy, 1996, "Remedial Design Work Plan for Remedial Actions at Operable Unit 5," Draft Final, Fernald Environmental Management Project, DOE, Fernald Area Office, Cincinnati, OH.



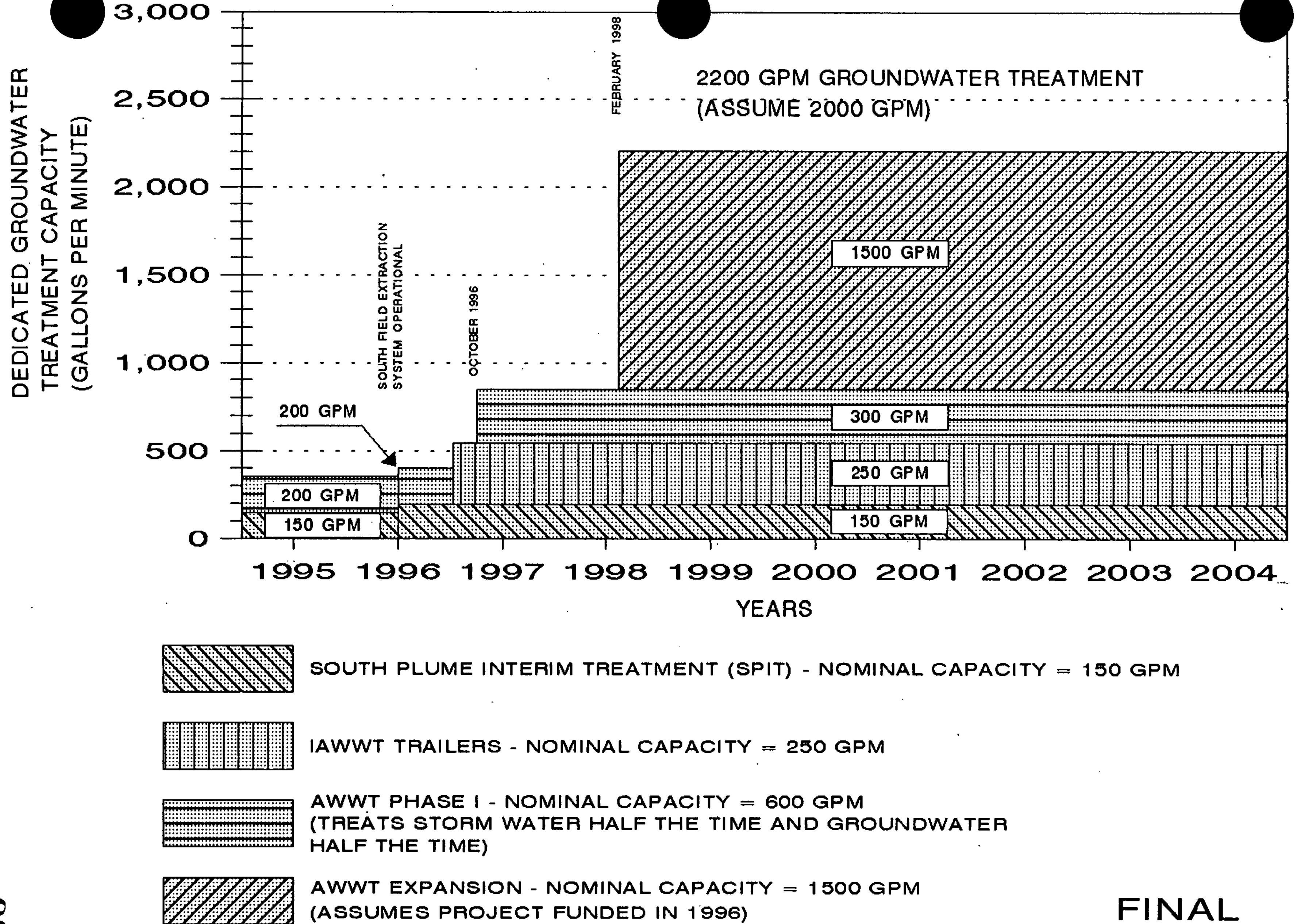
FINAL

——— Primary Flow

.... Secondary Flow (when excess capacity is available)

* System treats either storm water or groundwater, not both simultaneously

Figure D1. PROJECTED EFFLUENT FLOW DIAGRAM



FINAL

FIGURE D2. OPERATIONAL SCHEDULE OF COMBINED GROUNDWATER TREATMENT CAPACITY

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Appendix E

APPENDIX E

MODELING SIMULATIONS
TO SUPPORT DETERMINATION OF GROUNDWATER INJECTION DEPTH AND REVIEW OF OFF-PROPERTY LANDOWNER ACCESS CONCERNS

E.1.0 PURPOSE

This appendix presents thirty one (31) additional modeling simulations conducted in order to support the development of the final Baseline Remedial Strategy as presented in Section 5.0. These simulations were performed after the preliminary modeling work and evaluations as discussed in Section 4.0 were completed. Selection of the number and location of South Plume optimization wells, containment of the on-property plume, groundwater injection depth, compliance with the FEMP outfall limits, and implementation schedules of system modules were the major issues evaluated in these additional modeling simulations. Three (3) different uranium plume delineations were used in these simulations because modeling was taking place at the same time that additional uranium profile data were being collected vie the Geoprobe™ technique. These data were collected to verify the extent of the current uranium plume. Most of the modeling results presented in this appendix have been presented to and discussed with the regulatory agencies (i.e., the US and Ohio EPAs) in a series of technical meetings between January and March 1997.

E.1.1 FURTHER EVALUATIONS OF POTENTIAL SOUTH PLUME OPTIMIZATION WELLS

The preliminary baseline strategies described in Section 4.0 include four (4) new off-property wells (i.e., 1, 3N, 2N, and KN). These four (4) off-property wells were located on land owned by the same land owner. Locations of these wells are based on the synthetic "maximum" plume developed in the Operable Unit 5 FS (DOE 1995), which is a combination of all the well-specific maximum detected uranium concentrations before the end of 1993. As discussed in Section 5.1.2, the land owner has concerns regarding these wells. This appendix summarizes additional model simulations conducted to further evaluate the need for and the optimal location of each of these wells. Beginning in November of 1996, additional groundwater samples were collected using a Geoprobe™ to better delineate the uranium plume. The controlling document for this work was the Restoration Area Verification Sampling Program Project Specific Plan. As these additional uranium data became available, they were used to update the initial uranium plume in the groundwater model.

E.1.2 FURTHER EVALUATIONS OF GROUNDWATER INJECTION

The preliminary baseline strategies also include five (5) groundwater injection wells along the FEMP's southern fenceline. These groundwater injection wells were designed to minimize further cross-fenceline migration of the on-property uranium plume and to increase the contaminant flushing rate in the off-property area. However, groundwater injection may push the uranium plume, in the vicinity of the injection wells, deeper into the aquifer. Potential impacts of various groundwater injection depths on the vertical expansion of the uranium plume were further evaluated by conducting cross-sectional particle tracking simulations. The main purpose of these simulations was to provide necessary information for determining proper injection well screen intervals so that further vertical expansion of uranium plume can be minimized during the planned groundwater injection operation.

E.1.3 URANIUM PLUMES SIMULATED

Results of all the additional modeling simulations were considered when finalizing the Baseline Remedial Strategy presented in Section 5.0 of the main text. These modeling results also provide information regarding system design issues such as funding, schedule, piping layout, and land access for both initial drilling and future routine well maintenance.

Sections E.2.0 through E.4.0 of this appendix summarize the results of the additional thirty one (31) modeling simulations conducted. These simulations are organized into the three sections according to the initial uranium plume delineations used in the model. Sections E.2.0 and E.3.0 present the modeling simulations completed before the Geoprobe™ sampling results were used to update the uranium plume delineation (see Appendix G). The uranium plume presented in the South Plume Design, Monitoring, and Evaluation Program Plan (DMEPP) (DOE 1996a) was used as the initial uranium plume for the five (5) modeling simulations discussed in Section E.2.0. Section E.3.0 summarizes seven (7) particle tracking simulations which do not require a plume delineation. Section E.4.0 summarizes an additional nineteen (19) modeling simulations using one of the two (2) revised uranium plume depictions. The revised plume depictions reflect the DMEPP data as well as either partial or complete Geoprobe™ sampling data.

E.2.0 PREVIOUS SIMULATIONS BASED ON THE DMEPP PLUME

Modeling results summarized in this subsection were generated and presented to the private property owner during a consultation process to explain the system design options and purposes of each well for the South Plume Optimization Module in the Fall of 1996 before the Geoprobe™ sampling task was initiated. The uranium plume presented in the South Plume DMEPP was used to define the initial uranium plume for these five (5) simulations instead of the synthetic "maximum" plume modeled for the preliminary evaluations presented in Section 4.0. Before the Geoprobe™ sampling task was conducted (see Appendix G), the DMEPP plume was believed to be a more realistic delineation of the current off-property uranium plume than the synthetic "maximum" plume because the DMEPP plume is defined using uranium concentrations measured in the Types 2 and 3 monitoring wells in the past three years. A comparison between the DMEPP and the synthetic "maximum" plumes is shown in Figure E-1.

E.2.1 DEFINITIONS OF SCENARIOS

The well locations and operational schedules for five (5) scenarios were defined to address specific concerns. The operational schedules also consider the actual funding situation in FYs 97 through 99 as described in Section 5.2.2. Well 22 shown in Figures E-2 through E-6 indicates a contingent extraction well which may be used to improve the on-property cleanup time and was not simulated in these five scenarios. The main focus of evaluation for each of the five (5) scenarios are explained in the following paragraphs.

Scenario I - Figure E-2 shows the well locations for Scenario I. Wells 2N and KN were located further to the south from their original locations as specified in the preliminary baseline strategy shown in Figure 4-3. These new locations reflect the leading edge of the 20 ppb plume when these wells start operation in FY 99 (based on the DMEPP plume). These wells are located at the leading edge so they can intercept the complete plume. The off-property and fenceline extraction/injection rate schedule for this scenario between FYs 97 and 05 is listed in Table E-1.

Scenario II - Figure E-3 shows the well locations of Scenario II. Wells 2N and KN were eliminated in this scenario assuming that they can not be installed due to land access restraints. Four (4) existing South Plume wells will therefore need to be continuously operated to maintain hydraulic capture of the off-property plume. The off-property and fenceline extraction/injection rate schedule for this scenario between FYs 97 and 05 is listed in Table E-2.

Scenario III - Figure E-4 shows the well locations of Scenario III. Wells 2N and KN were relocated just north of Willey Road to place them on FEMP property. This scenario was developed to evaluate the option of first using extraction wells to reduce the off-property plume. The injection operation (wells 8 through 12) will be delayed to allow Wells 2N and KN to recover some off-property uranium mass from the on-property area until the projected recovery efficiency diminishes. Four (4) existing South Plume wells will also need to be continuously operated to maintain hydraulic capture of the off-property plume. The off-property and fenceline extraction/injection rate schedule for this scenario between FYs 97 and 05 is listed in Table E-3.

Scenario IV - Figure E-5 shows the well locations of Scenario IV. Wells 2N and KN were relocated just north of Willey Road to place them on FEMP property, with Wells 8 and 10 also used for extraction. This scenario was developed to evaluate the option of using extraction wells instead of injection wells to create a hydraulic barrier along the fenceline and recover the eastern portion of the off-property plume. Injection wells 9 and 11 were eliminated. The off-property and fenceline extraction/injection rate schedule for this scenario between FYs 97 and 05 is listed in Table E-4.

Scenario V - Figure E-6 shows the well locations of Scenario V. Well KN was eliminated in this scenario assuming that it can not be installed due to land access restraints, and 2N was positioned at its original location for the preliminary baseline strategy. It was also assumed that Wells 2N, 1 and 3N will still start operation in FY 99. Four (4) existing South Plume wells will need to be continuously operated to maintain hydraulic capture zone of the off-property plume. The off-property and fenceline extraction/injection rate schedule for this scenario between FYs 97 and 05 is listed in Table E-5.

E.2.2 MODELING RESULTS

The simulated groundwater table drawdown contours at FY 99, maximum extent of the off-property plume, and residual uranium plume at the end of FY 03 for each of the five (5) scenarios were evaluated. FY 99 is when the maximum off-property drawdown is expected for each of these scenarios. The end of FY 03 is just prior to the "apparent" K_d transition in the South Field and South Plume areas (see Appendix A) which is assumed to take place in the model simulations. After the K_d transition is implemented, differences between scenarios in the off-property area become insignificant. These modeling results demonstrate the relative performance of each of the five (5) scenarios in terms of hydraulic impact, plume expansion, and potential range of aquifer cleanup time. Although the uranium plume used to simulate these scenarios does not mimic the most up to date plume delineation based on the Geoprobe™ data collected after these simulations, most of the conclusions presented in the draft report regarding relative performance of these five (5) scenarios are still valid. Following is a summary of these conclusions:

Drawdown - As can be seen in Figures E-7, E-8, E-9, E-10, and E-11; Scenario IV has the maximum drawdown in the immediate off-property area; Scenario V has the maximum drawdown around the existing South Plume recovery wells; while Scenario I has the minimum overall off-property drawdown.

Capture Zone - Particle tracking from the fenceline extraction wells are also shown in Figures E-12 and E-13. As can be seen in these two figures, capture zones of the fenceline extraction wells do not extend significantly into the off-property area nor do they cover the entire off-property plume.

Plume Expansion - Comparison of the simulated maximum extent of the off-property plume indicate that the five (5) scenarios result in similar degrees of expansion, overall. Scenario IV has less overall expansion compared to the others, while Scenario III shows the greatest amount of expansion. The differences in plume expansion between Scenarios I and II are relatively insignificant.

Efficiency - Simulated off-property plumes at the end of FY 03 for the five (5) scenarios were also evaluated. Scenario II has the minimum off-property plume while Scenario III has the maximum. Locations of the off-property plumes in Scenarios III and IV are different from the other three scenarios. In scenarios with pumping operations along the fenceline, the plumes will tend to linger along the fenceline due to competing upgradient and downgradient hydraulic forces.

Most importantly these modeling results show that scenarios with groundwater injection will generally provide better overall performance than scenarios with groundwater extraction along the FEMP's southern fenceline.

E.3.0 HYDRAULIC EVALUATION OF GROUNDWATER INJECTION

Although the previous modeling indicate that groundwater injection along FEMP's southern fenceline is promising, the injection depths, as simulated in the preliminary baseline strategies described in Section 4.0, need to be fine tuned in order to better control the potential vertical expansion of the uranium plume and to help ensure that the desired benefits of groundwater injection are realized. Concerns regarding groundwater injection increased when Geoprobe™ sampling results confirmed a deeper than anticipated extent of the uranium plume near the planned injection Well #10 and #11. Important information provided by results of the Phase I and initial Phase II Geoprobe™ sampling include the following:

- Higher total uranium concentrations exist between the Storm Sewer Outfall Ditch (SSOD) and the FEMP southern fenceline than previous estimated;
- Evidence for downward plume expansion, possibly due to a localized higher intermittent surface infiltration rate under a pond, near injection Well #10 and #11; and
- A potentially larger off-property plume near the potential location of South Plume Optimization Well 2N.

Due to this information and the increased concerns regarding injection, additional modeling simulations were conducted to further evaluate the effects of groundwater injection, while the remaining Phase II Geoprobe™ sampling events were being completed. Because the Geoprobe™

sampling results were not yet available to completely revise the previous uranium plume delineation (i.e., the DMEPP plume), these additional modeling simulations focused on the hydraulic effects of groundwater injection using the forward particle tracking technique. These modeling simulations were conducted for the following purposes:

- To evaluate the potential for downward plume expansion at the injection well locations;
- To find possible solutions for minimizing further downward plume expansion, if necessary;
- To evaluate the potential of further cross-fenceline plume migration;
- To find possible solutions for minimizing further cross-fenceline plume migration, if necessary;
- To provide information (i.e., well screen depth) required to continue the on-going injection well installation; and
- To provide information (e.g., new well locations) for the on-going design efforts for the Phase I South Field Module and the South Plume Optimization Module.

E.3.1 DEFINITION OF SCENARIOS

Table E-6 summarizes the seven (7) scenarios developed to evaluate the hydraulic performance of groundwater injection. Scenarios 1 through 3 were used to compare the flow patterns of the injected water when injected from three (3) different depth intervals. The effects of different injection depths on groundwater flow paths originating from areas north of the injection wells (i.e., upgradient) were also compared in these three (3) scenarios.

After the optimal range of injection depth interval was selected based on the results of the first three (3) scenarios, Scenarios 4 through 7 were used to select an approach for considering the need for additional on-property extraction to better reduce cross-fenceline migration of the uranium plume. Potential effects of the South Plume Optimization Module and the higher uranium concentrations found in areas south of the SSOD during the Phase I Geoprobe™ sampling were considered in these scenarios. Figure E-14 shows locations of the particle seeding points and extraction/injection wells simulated in these scenarios.

E.3.2 MODELING RESULTS

Figures E-15 through E-17 show the cross-sectional view of the particle tracking simulation results of Scenarios 1 through 3, respectively. Only the fenceline injection wells and the South Plume recovery wells were simulated in these three (3) scenarios. After comparing Figures E-15 through E-17, it was concluded that injection at lower elevations can reduce downward plume expansion. Field injection test results and subsequent geochemical analyses (DOE 1996b), shows that available water for injection is chemically incompatible with deeper aquifer groundwater and may cause significant iron precipitation if injected too deep. A portion of the upgradient plume may also flow over the injection zone as shown in figure E-17, if the injection screen is situated too deep.

Given these considerations, the most promising injection depth range is between 510 feet to 460 feet above mean sea level (i.e., within the SWIFT GMA Model Layer 2) as simulated in Scenario 2. Well-specific injection depth intervals within the 50-foot range will need to be determined based on the local uranium concentration profiles. The injection interval (usually a 15- or 20-foot screen) should be within the major portion of the uranium plume, but remain in the general interval between 510 feet to 460 feet. The screen should be situated as high up as practical within the 50-foot interval to reduce the likelihood of significant iron precipitation problems, but low enough to intercept the greater than 20 ppb total uranium plume where possible.

Different degrees of potential vertical plume expansion and breakthrough around the injection wells were observed in Scenarios 1 through 3. Additional scenarios with South Field Phase I Module extraction wells, selected potential South Plume optimization wells, and the contingent Well 22 were simulated to determine possible approaches for reducing potential vertical expansion and cross-fenceline migration of the on-property uranium plume. The groundwater injection depth was set in Model Layer 2 for all the follow up scenarios. Figures E-18 through E-23 show the results for Scenarios 4 through 7 as defined in Table E-6. In general, results of Scenarios 4 through 7 provided the following information regarding the expected effectiveness of various combinations of groundwater injection wells and on- and/or off-property extraction wells for containing the on-property uranium plume:

- Injection along the fenceline will significantly reduce, but not completely stop further cross-fenceline plume migration;
- An injection depth which is too shallow may push the plume deeper;

- An injection depth which is too deep may allow the shallower plume to migrate past the injection area;

- There will be notable continuous cross-fenceline plume migration between the injection wells during FY 98 before additional on-property extraction wells start operation;

- Operation of the South Plume Optimization Module extraction wells can potentially increase cross-fenceline plume migration; and

- Extraction Well 22 will significantly reduce cross-fenceline plume migration (see Figures E-21 and E-23).

As shown in Figures E-20 and E-22, potential downward plume expansion can also be controlled/minimized by operating the on-property contingent extraction Well 22 between the southern fenceline and the SSOD within a very thick portion of the greater than 20 ppb total uranium plume as indicated by available Geoprobe™ profile sampling results. Other benefits of operating Well 22 may also include:

- Directly captures the significant uranium plume located just south of the SSOD;
- Increases the effective capture zone of the South Field System;
- Improves uranium mass recovery efficiency of the South Field Module; and
- Shortens the aquifer cleanup time.

E.3.3 RECOMMENDATIONS

Based on results of the hydraulic simulations described in the previous subsection, the following three (3) important recommendations are made:

- Continue with the installation of the Injection Demonstration System and target the top of injection screens to the 19-foot depth range between 509 feet amsl to 490 feet amsl;

- Add the contingent extraction Well 22 to the Phase I South Field Module design; and

- Minimize the time lag between commencement of the Injection Demonstration System, the South Plume Optimization Module, and the expanded South Field Phase I Module.

The hydraulic modeling simulation results and resultant recommendations were presented in a technical meeting between DOE and the regulatory agencies on January 13, 1997.

E.4.0 SIMULATIONS BASED ON THE UPDATED URANIUM PLUMES

Additional modeling simulations were conducted using the most up to date uranium plume; the DMEPP plume updated with the new Geoprobe™ sampling results obtained in early 1997. As described in Appendix G, three (3) phases of Geoprobe™ sampling at a total of nineteen (19) locations were conducted to better delineate the current uranium plume south of the SSOD and in the off-property area to support the design of the aquifer restoration system.

Modeling simulations conducted using the updated uranium plume were designed to provide information for finalizing the following decisions in the Baseline Remedial Strategy:

- What is the need for each of the potential South Plume optimization wells;
- What are the optimal locations of the critical (i.e., feasible and beneficial) South Plume optimization wells;
- What are the optimal pumping rates of the critical South Plume optimization wells; and
- What start up and overall operational schedule should be used to operate the Fenceline Injection, the South Plume Optimization, and the South Filed Phase I Modules.

Because the Geoprobe™ sampling task was initiated after the draft Baseline Remedial Strategy Report was submitted, results of the Geoprobe™ sampling task and the additional modeling simulations were not available in the previous draft. However, the Geoprobe™ sampling results, updated uranium plume, and results from the additional modeling simulations have been presented to and discussed with the regulatory agencies in a series of technical information exchange meetings between January and March 1997.

E.4.1 UPDATED URANIUM PLUME

The three-dimensional delineation of the current greater than 20 ppb uranium plume has been updated according to all the available data including the latest Geoprobe™ sampling results. The initial uranium plume in the SWIFT GMA model was also revised accordingly. Due to limitations of the model structure, it is necessary to define the continuous uranium plume in the model by simplifying it into discrete conservative layer- and block-specific concentrations.

E.4.1.1 Summary of the Geoprobe™ Sampling Results

The Geoprobe™ sampling task was conducted in three (3) Phases between October 1996 and May 1997. Overall nineteen (19) uranium concentration profiles in the aquifer were produced from the Geoprobe™ sampling events. Six (6) sampling locations were completed during Phase I to better define the uranium plume around Well 3069, where the greater than 20 ppb uranium plume is located deeper. Because of the proximity of the planned fenceline injection wells, understanding the vertical extent of the uranium plume and potential mechanisms causing the vertical expansion of the plume in this area is important. Eight (8) sampling locations were completed during Phase II to better define the current level of uranium concentrations in the area between the SSOD and Willey Road, as well as the southeastern extent (i.e., the 20 ppb contour) of the South Plume in the off-property area. During Phase III, four (4) more uranium concentration profiles were obtained in the area between Paddys Run Road and the potential optimization Well 1 and 3N locations. An additional profile was obtained east of Well 2398 and north of Willey Road to verify the location of the eastern edge of the 20 μg/L total uranium plume. Figure E-24 shows all the Geoprobe™ sampling locations.

Important observations made from the twenty seven (27) concentration profiles obtained from Geoprobe™ sampling and the South Field Phase I well locations profiles are summarized below:

- The plume is primarily in the top 40 feet of the saturated zone.
- The location-specific maximum uranium concentrations are detected within 20 feet of the groundwater table in most areas.
- Maximum uranium concentrations are detected about 20 feet below the groundwater table at eleven (11) locations.
- At eight locations (i.e., 31565, 31564, 31561, 12192, 12193, 12228, 12237, and 12241) the detected maximum uranium concentration is more than 20 feet below the groundwater table. Seven (7) of the eight (8) locations are close to areas of higher vertical infiltration (e.g., near Paddys Run, SSOD, and/or on edge of till). The only off-property location away from Paddys Run where the maximum uranium concentration is greater than 20 feet below the groundwater table (i.e., at 30 feet in 12228) may be due to pumping of a close by home owner's well.
- The 20 ppb plume reaches the typical Type 3 well screen elevation (i.e., about 450 feet amsl) in four (4) on-property locations (i.e., 12230, 12194, 12193, and 3069) along the southern branch of the SSOD and three (3) off-property locations (i.e., 3125, South Plume recovery well #1 and #2) around the western portion of the South Plume recovery well field.

- The screen intervals of South Plume recovery well #3 and #4 are at an proper elevation (i.e., at the same elevation as the uranium plume) to intercept the eastern portion of the South Plume.
- In most areas further away from the sources of the plume (i.e., the SSOD and Paddys Run), the plume becomes thinner with maximum concentrations found below the groundwater table, so that some existing Type 2 monitoring wells can potentially miss the plume (e.g., 2880 and 2881).
- The current interpretation of the off-property uranium plume extent is considerably larger than the DMEPP plume as shown in Figure E-1 due to the incorporation of the new Geoprobe™ data.

Together with the recent data collected for the DMEPP (i.e., from the existing Type 2 and Type 3 monitoring wells), the nine (9) uranium concentration profiles from the Phase I South Field extraction well borings installed in 1996, the recent South Plume recovery well concentration data, and the nineteen (19) Geoprobe™ uranium concentration profiles sufficiently define the vertical and lateral extents of the current uranium plume in the South Plume area. More details of the Geoprobe™ sampling task are described in Appendix G.

E.4.1.2 Revised Initial Uranium Plume for the Modeling Purposes

The updated delineation of the current uranium plume was incorporated into the SWIFT GMA model for additional modeling simulations to provide necessary information for finalizing the Baseline Remedial Strategy. Because the computer model consists of discrete model blocks and layers, the continuous actual uranium plume in the aquifer needs to be presented in the model with block-specific concentration values. Conservative procedures were used to determine the block-specific uranium concentrations. In general, location-specific maximum concentrations were assigned over both model layers 1 and 2. The manually contoured maximum concentration levels (see Appendix G) were used to determine the location-specific maximum concentrations.

Figures E-25 and E-26 show two updated uranium plumes as presented in the SWIFT GMA model for additional modeling simulations. The plume shown in Figure E-25 was developed before the Phase III Geoprobe™ sampling was completed. The plume shown in Figure E-26 was developed after the entire Geoprobe™ sampling task was completed. The estimated concentrations in the area around and northwest of the potential Well 3N location as shown in Figure E-25 needed to be slightly decreased after the Geoprobe™ sampling results in this area became available. The modeling results using the updated plumes will tend to overestimate potential maximum extent of the plume due to the larger uranium mass in the conservatively assumed block-specific concentrations. These conservative plumes are adequate for relative comparisons of potential scenarios and will result in a conservative Baseline Remedial Strategy regarding the groundwater treatment capacity and cleanup time requirements. A modeling plume developed based on results of a more realistic 3-D kriging technique was also used in simulation of the final Baseline Remedial Strategy as described in Section 5.0.

E.4.2 DEFINITION OF THE ADDITIONAL SCENARIOS

Potential scenarios were developed and simulated to evaluate various design and operational parameters of the overall groundwater remedial system to be included in the Baseline Remedial Strategy. Based on the primary parameters to be evaluated in each of the scenarios, these scenarios are separated into three (3) groups and discussed in the following three (3) subsections. As mentioned earlier, the modeling and Geoprobe™ sampling activities were conducted simultaneously. Two (2) slightly different uranium plumes in the off-property area (see Figures E-25 and E-26) were used when simulating these additional scenarios. The finalized uranium plume as shown in Figure E-26 was only used for the third group of scenarios. However, the minor differences in the initial uranium plume will not significantly affect the major conclusions obtained from the modeling results of the first two (2) groups of the additional scenarios.

In order to prevent any significant increases of hydraulic impact to the nearby industrial site, a maximum per well extraction rate of 400 gpm and a maximum system total extraction rate of 1000 gpm were imposed on all the potential South Plume optimization wells in all the additional scenarios. The 400 gpm per well extraction rate limit was selected considering the drawdown observed in the existing South Plume recovery wells which are currently operated at 300 to 400 gpm. The 1000 gpm maximum total extraction rate was selected considering the planned total groundwater injection rate of 1000 gpm along the FEMP southern fenceline. It is expected that, if the total additional extraction rate from the optimization wells does not exceed the injection rate, then a significant increase of the hydraulic impact will not occur.

It is also important to note that the regulatory agencies were actively involved in the development of these scenarios as well as the selection of important performance measures to be used for comparing these scenarios. The step-by-step developments of the three (3) groups of scenarios and associated focus of the evaluations reflect the decision-making process involving both the DOE and the regulatory agencies when finalizing the Baseline Remedial Strategy described in Section 5.0 of the main text. The following subsections define the additional scenarios simulated and describe the main focus in each step of the evaluation.

E.4.2.1 Scenarios for Start-Up Schedule Evaluation

The first group include scenarios in which the four (4) potential optimization wells (i.e., Wells 1, 2N, 3N, and KN) are at their initially selected locations as shown in Figure E-27. These preliminary locations were expected to reduce future plume expansion and increase mass removal efficiency based on previous modeling results (see Section E.2.0). Different combinations of the start-up times for the Fenceline Injection Module, Well 22, South Plume Optimization Module, and South Field Phase I Module were simulated in twelve (12) potential scenarios (designated as Scenarios A-1 through A-12). The main purpose of these scenarios was to provide information for determining the proper sequence in which system modules can be brought on line. Effects of including and/or excluding particular wells as well as delaying the operation of specific system modules were also evaluated by comparing the simulated performances of these scenarios. Table E-7 summarizes the twelve (12) scenarios in this group. The uranium plume shown in Figure E-25 was used as the initial conditions to simulate the performance of these scenarios.

E.4.2.2 Scenarios for Optimization Well Need/Location Evaluation

After evaluating results of the first twelve (12) scenarios, the acceptable start-up sequence and schedule of each of the system components can be determined. However, after discussing results of the first group of scenarios with the regulatory agencies, it was determined that more information was required to finalize the need for and location of the four (4) potential optimization wells. As requested by the regulatory agencies, five (5) additional scenarios were developed and simulated to provide information to support decisions regarding selection of the feasible and most beneficial South Plume optimization wells and final locations of the selected wells. In addition to demonstrating the projected overall progress of groundwater remediation of each scenario using simulated uranium plumes, well-specific and cumulative uranium mass removal rates of the potential optimization wells were also calculated for these scenarios.

Table E-8 defines these five (5) additional scenarios (designated as Scenarios B-1 through B-5). The five (5) scenarios include various two-well patterns using extraction wells at potential Well 1, 3N, and/or 2N locations for evaluation. Well 22 was operated in all five (5) scenarios. Locations of the wells included in these five (5) scenarios are also shown graphically in Figures E-28 through E-31. In general, the location of Well 2N was strategically moved about 350 feet west from its previously simulated location (see Figure E-27) to increase mass removal efficiency. The uranium plume shown in Figure E-25 was also used as the initial conditions to simulate the performances of these five (5) scenarios.

E.4.2.3 Scenarios for Optimization Well Extraction Rate Evaluation

In order to further evaluate the impacts on the FEMP outfall limits specified in the Operable Unit 5 ROD by combining the extracted groundwater from the potential South Plume optimization wells and the existing South Plume recovery wells, two (2) more scenarios were developed and simulated. As described in Section 3.1.2, the FEMP Great Miami River outfall limits include a uranium concentration limit of 20 ppb and a uranium mass limit of 600 pounds per year. Table E-9 summarizes these two (2) scenarios (designated as Scenarios C-1 and C-2). Two total extraction rates (i.e., 800 gpm and 500 gpm) from Wells 1 and 2N were simulated in these scenarios using the finalized uranium plume as shown in Figure E-26.

The simulated well-specific extracted groundwater concentrations from these two (2) scenarios were used to estimate the outfall conditions under both the combined- and separated-line designs for the South Plume Optimization Module. Figure E-32 shows the assumed groundwater treatment capacity and the conceptual flow routing network used in this analysis. Additional details regarding the groundwater treatment capacity are presented in Appendix D.

E.4.3 MODELING RESULTS

Modeling results for all the additional scenarios defined in the previous section are summarized in this section. Generally the SWIFT GMA modeling output include data necessary to describe the following conditions:

- Groundwater table elevation;
- Groundwater flow field;
- Time-varying concentration distribution in the aquifer;
- Well-specific extracted groundwater concentration;

- Extracted uranium mass;
- Combined outfall concentrations; and
- Cleanup time.

After the groundwater flow field is simulated, the STLINE code can also be used to simulate backward retarded and/or unretarded particle tracks from each extraction well to determine the system or well-specific capture zones. Based on the main focus of each group of the additional scenarios, selected SWIFT GMA model outputs were post-processed and evaluated. The following three (3) subsections describe the modeling results for scenarios in each of the three (3) groups, separately.

E.4.3.1 Results for Start-Up Schedule Evaluation

The impacts due to various start-up schedule/sequence and inclusion/exclusion of specific wells in the South Plume Optimization and the South Field Phase I Modules were evaluated using the modeling results of the first group of scenarios defined in Section E.4.2.1. The range of the maximum uranium plume extent among the twelve (12) scenarios (see Figure E-33), the residual plume in Model Layer 1 of each scenario at the end of FY 03 before the uranium K_d transition (see Appendix A) in the simulations (see Figures E-34 through E-45), and estimated capture zones (see Figures E-46 through 49) were determined from the modeling results.

The major findings from modeling results of these twelve (12) scenarios include:

- The most significant off-property plume expansion occurs in the first year when only the South Plume Recovery Well System is in operation. The annual expansion rates gradually decrease in the following years when more extraction wells are brought on-line and the uranium mass depleted. Given the very steep concentration gradient along the edge of the targeted initial uranium plume in the model, early expansions of the plume may be partially due to the way SWIFT models the dispersion process. Actual plume expansion during the first year may not be as dramatic as that predicted.

- All twelve (12) scenarios have hydraulic capture zones that eventually will cover the targeted plume.

- As expected, scenarios with more wells and earlier starts perform better (i.e., less expansion and smaller residual plume). However, differences are not very significant in the maximum plume extents among all the scenarios.

- Contributions of Well 22 are very significant.

- Contribution of Well KN is relatively insignificant since its capture zone is to the northeast, (due to injection Well 12) away from the main portion of the uranium plume.

- Delay of injection (i.e., Scenario A-4) results in a more significant off-property plume.
- Proper sequencing of Well 1, 3N, and 2N operations probably will further improve the system performance (i.e., reduce the off-property 50 ppb plume at the end of FY 03).
- With source loading terminated and the expected K_d transition, the off-property area can be cleaned up by FY 04 under all twelve (12) scenarios.

The modeling simulation results of these twelve (12) scenarios were presented in a technical meeting between DOE and the regulatory agencies on March 18, 1997.

E.4.3.2 <u>Results for Optimization Well Need/Location Evaluation</u>

The mass removal efficiency of each potential South Plume optimization well and performances of various two-well patterns using extraction wells at potential Well 1, 3N, and/or 2N locations as well as an additional off-property injection well were evaluated using the modeling results of the second group of scenarios defined in Section E.4.2.2. The maximum plume extent and the residual plume in Model Layer 1 of each scenario at the end of FY 03 before the uranium K_d transition (see Appendix A) in the simulations (see Figures E-50 through E-54), the estimated capture zones (see Figures E-55 through 60), and annual and cumulative mass removal rates from the South Plume optimization wells included in each scenario (see Tables E-10 and E-11) were determined from the modeling results of the five (5) scenarios.

The major findings from modeling results of these five (5) scenarios include:

- Mass removal rates from Well KN (see Tables E-10 and E-11) are relatively insignificant (i.e., only about 10 percent of the other potential optimization wells' rates and about 4 percent of the total mass removed by the four optimization wells). This confirms the expansions of the plume in the area as demonstrated in the plume maps is not significant (see Figure E-33 and Figures E-50 through E-54).
- As expected, the new Well 2N location increases mass removal rate but results in a slight expansion of the edge of the plume when compared to the previous location (see Figure E-27).
- Mass removal rates from the main portion of the South Plume using the two-well patterns (i.e., Scenarios B-3 and B-5) are comparable with using the three-well patterns (i.e., Scenarios A-7 and B-1).

- Due to higher mass removal rates in the South Plume area, all the evaluated scenarios potentially may exceed the outfall concentration and/or mass discharge limits, particularly in the first several years of operation.

The modeling simulation results of these five (5) scenarios were presented in a technical meeting between DOE and the regulatory agencies on March 25, 1997.

E.4.3.3 Results for Optimization Well Extraction Rate Evaluation

The aquifer remedial performance and potential impacts to the FEMP outfall conditions were evaluated using the modeling results of the third group of scenarios defined in Section E.4.2.3. The maximum plume extent and the residual plume in Model Layer 1 of each scenario at the end of FY 03 before the uranium K_d transition (see Appendix A) in the simulations (see Figures E-61 and E-62), the estimated capture zones (see Figures E-63 and 64), and annual and cumulative mass removal rates from the two (2) South Plume optimization wells (i.e., Well 1 and 2N) included in Scenarios C-1 and C-2 (see Tables E-12 and E-13) were determined from the modeling results. Tables E-14 and E-15 present the estimated outfall conditions using combined and separate discharge lines for the South Plume Optimization Module from the existing force main under each of the two (2) scenarios before the end of FY 03.

The major findings from modeling results of these two (2) scenarios include:

- Simulated maximum extents of the uranium plume for Scenarios C-1 and C-2 are not significantly different.

- As expected, the mass removal rates from Well 1 and 2N are generally proportional to the extraction rates simulated. Also, the residual off-property 50 ppb plume at the end of the FY 03 is smaller when a higher total extraction rate is used (i.e., the C-1 case).

- As shown in Tables E-14 and E-15, the outfall concentration limit was exceeded in the combined and separate discharge line cases for both scenarios.

- Under the combined discharge line assumption, Scenario C-1 (i.e., 800 gpm total extraction rate for the South Plume Optimization Module) will result in a higher maximum outfall concentration, but when the outfall concentration limit is exceeded, the duration will be shorter.

- Under the separate discharge line assumption, estimated outfall concentrations are very similar in both scenarios because the extracted groundwater from the South Plume Optimization Module is all treated without mixing with the rest of the South Plume flow.

- The outfall uranium mass discharge limit (i.e., 600 pounds per year) will not be exceeded.

- In order to satisfy the FEMP's outfall uranium concentration limit, the total extraction rate (i.e., 1000 gpm potential) of the South Plume Optimization Module may not be fully utilized in the first several years of operation.

- A separate discharge line (if installed) for the South Plume Optimization Module can reduce outfall concentration, because the flow with higher uranium concentration can be preferentially treated.

- Under the single line scenario, the combined South Plume flow should be split at the South Field Valve House (to be built as part of the South Field Phase I Module) for partial treatment to fully utilize the available treatment capacity and to reduce the outfall concentration. This option was assumed when estimating the outfall concentrations presented in Tables E-14 and E-15 for both the single and combined line cases.

Although the estimated outfall concentrations exceed the limit in earlier years of operation, it is important to point out that the uranium plume (as shown in Figure E-26) used in these modeling simulations was very conservative and can result in overestimated outfall concentrations. For example, the current combined flow from the four (4) existing South Plume recovery wells is around 20 ppb, which is significantly lower than the model estimated 28.8 ppb for 1997. It is expected that the actual outfall concentrations under the operational conditions simulated in Scenario C-2 (i.e., 500 gpm total extraction rate for the South Plume Optimization Module) will likely be within the limit and the total extraction rate of South Plume Optimization Module can be gradually increased during the operation.

The mass removed by each remediation system module for scenarios C-1 and C-2 is shown in Tables E-16 and E-17 respectively.

After all the simulations described in this appendix were completed, a more realistic plume was developed by 3-D kriging technique and was used in simulation of the final Baseline Remedial Strategy as described in Section 5.0 instead of the manually contoured uranium plumes shown in Figures E-25 and E-26. Estimated important performance measures of the Baseline Remedial Strategy including the outfall conditions are also presented in Section 5.0 using the kriged plume.

E.5.0 SUMMARY

Thirty one (31) additional modeling simulations were conducted to support the development of the final Baseline Remedial Strategy. Three (3) different updated uranium plume delineations were used in these simulations because modeling was taking place at the same time that additional Geoprobe™ data were being collected to better delineate the uranium plume south of the SSOD and the off-property area.

The regulatory agencies were actively involved in the development of the modeling scenarios as well as the selection of important performance measures used for comparing these scenarios. The step-by-step developments of the scenarios and associated focus of evaluations reflect the decision-making process involving both the DOE and the regulatory agencies when finalizing the Baseline Remedial Strategy. Most of the modeling results presented in this appendix have also been presented to and discussed with the regulatory agencies in a series of technical meetings between January and March 1997.

Results of all the additional modeling simulations described in this appendix were considered when selecting the South Plume optimization wells, adding an on-property extraction well to better contain the on-property plume, determining well-specific groundwater injection depth, demonstrating compliance with the FEMP outfall limits, and finalizing the implementation schedules of system modules included in the final Baseline Remedial Strategy presented in Section 5.0 of the main text. These modeling results also provide more information for the decision-makers regarding the system design issues such as funding schedule, piping layout, and area access for future routine well maintenance. A more realistic plume was developed by 3-D kriging technique and was used in simulation of the final Baseline Remedial Strategy selected and described in Section 5.0.

REFERENCES

U.S. Department of Energy, 1995, "Feasibility Study Report for Operable Unit 5," Final, Fernald Environmental Management Project, DOE, Fernald Area Office, Cincinnati, OH.

U.S. Department of Energy, 1996a, "South Plume Removal Action Design Monitoring Evaluation Program Plan, System Evaluation Report, For July 1, 1995 - December 31, 1995," Fernald Environmental Management Project, DOE, Fernald Area Office, Cincinnati, OH.

U.S. Department of Energy, 1996b, "Phase II South Field Injection Test Report For Operable Unit 5," Fernald Environmental Management Project, DOE, Fernald Area Office, Cincinnati, OH.

TABLE E-1

SCENARIO I PUMPING SCHEDULE BY AREA

	1997	1998	1999-2001	2002-2003	2004-2005
Off Property	1400	1400	1500	1500	0
Fenceline	0	-1000	-1000	-1000	0
On Property	0	0	1300	1300	4800
Northern Injectors (including 13, 14, and 16)	0	0	0	0	-1600

Notes: + = pumping
- = injecting

TABLE E-2

SCENARIO II PUMPING SCHEDULE BY AREA

	1997	1998	1999-2001	2002-2003	2004-2005
Off Property	1400	1400	2000	2000	0
Fenceline	0	-1000	-1000	-1000	0
On Property	0	0	1300	1300	4800
Northern Injectors (including 13, 14, and 16)	0	0	0	0	-1600

Notes: + = pumping
- = injecting

TABLE E-3

SCENARIO III PUMPING SCHEDULE BY AREA

	1997	1998	1999-2001	2002-2003	2004-2005
Off Property	1400	1400	2000	2000	0
Fenceline	0	0	0	-1000	0
On Property	0	0	1600	1300	4800
Northern Injectors (including 13, 14, and 16)	0	0	0	0	-1600

Notes: + = pumping
- = injecting

TABLE E-4

SCENARIO IV PUMPING SCHEDULE BY AREA

	1997	1998	1999-2001	2002-2003	2004-2005
Off Property	1400	1400	1200	1200	600
Fenceline	0	0	800	800	800
On Property	0	0	1300	1300	4200
Northern Injectors (including 13, 14, and 16)	0	0	0	0	-1600

Notes: + = pumping
- = injecting

TABLE E-5

SCENARIO V PUMPING SCHEDULE BY AREA

	1997	1998	1999-2001	2002-2003	2004-2005
Off Property	1400	1400	2200	2200	0
Fenceline	0	-1000	-1000	-1000	0
On Property	0	0	1300	1300	4800
Northern Injectors (including 13, 14, and 16)	0	0	0	0	-1600

Notes: + = pumping
- = injecting

TABLE E-6

HYDRAULIC EVALUATION SCENARIOS

SCENARIO	OPERATIONAL CONDITIONS	MAJOR ISSUES EVALUATED
1	South Plume recovery wells pumping at 1400 gpm and injection at 1000 gpm in the Model Layer 1 (525' to 510') along the FEMP southern fenceline.	Vertical plume expansion; and Containment of the on-property plume.
2	South Plume recovery wells pumping at 1400 gpm and injection at 1000 gpm in the Model Layer 1 (510' to 460') along the FEMP southern fenceline.	Vertical plume expansion; and Containment of the on-property plume.
3	South Plume recovery wells pumping at 1400 gpm and injection at 1000 gpm in the Model Layer 1 (460' to 440') along the FEMP southern fenceline.	Vertical plume expansion; and Containment of the on-property plume.
4	Add South Plume optimizational wells 1 and 3N (600 gpm total) and the South Field Phase I extraction wells (1300 gpm total) to Scenario 2.	Containment of the on-property plume.
5	Add South Plume optimizational wells 1, 3N, and 2N (750 gpm total) and the South Field Phase I extraction wells (1300 gpm total) to Scenario 2.	Containment of the off-property plume.
6	Add South Plume optimizational wells 1 and 3N (600 gpm total), the South Field Phase I extraction wells (1300 gpm total), and Well 22 (200 gpm) to Scenario 2.	Containment of the on-property plume.
7	Add South Plume optimizational wells 1, 3N and 2N (750 gpm total), the South Field Phase I extraction wells (1300 gpm total), and Well 22 (200 gpm) to Scenario 2.	Containment of the on- and off-property plumes; and Improvement of remedial efficiency.

TABLE E-7

START-UP SCHEDULE EVALUATION SCENARIOS

	MODULE	STARTING	TIME		(Rate	gpm)	
SCENARIO	SOUTH PLUME (1400)	FENCELINE INJECTION (-1000)	1 AND 3N (600)	2N (150)	KN (150)	22 (200)	SOUTH FIELD PHASE I (1300)
A-1	1997	1998	1999	NU	NU	NU	1999
A-2	1997	1998	1999	1999	NU	1999	1999
A-3	1997	1998	1999	1999	1999	1999	1999
A-4	1997	1999	1999	1999	1999	1999	1999
A-5	1997	1998	1999	NU	NU	1998	1999
A-6	1997	1998	1999	1999	NU	1998	1999
A-7	1997	1998	1999	1999	1999	1998	1999
A-8	1997	1998	1998	NU	NU	1998	1999
A-9	1997	1998	1998	1998	NU	1998	1999
A-10	1997	1998	1998	1998	1998	1998	1999
A-11	1997	1998	1998	1998	1998	1998	1998
A-12	1997	1997	1997	1997	1997	1997	1997

Note: NU Not Used

TABLE E-8

OPTIMIZATION WELL NEED/LOCATION EVALUATION SCENARIOS

	STARTING					TIMES	(FY)		
SCENARIO	SOUTH PLUME	FENCELINE INJECTION	OFF-PROPERTY INJECTION	1	3N	2N	KN	22	SOUTH FIELD PHASE I
B-1	1997	1998	1999	1999	1999	1999	1999	1998	1999
B-2	1997	1998	N/A	1999	1999	1999	1999	1998	1999
B-3	1997	1998	N/A	N/A	1999	1999	1999	1998	1999
B-4	1997	1998	N/A	N/A	1999-2001	1999	1999	1998	1999
B-5	1997	1998	N/A	1999	N/A	1999	1999	1998	1999

		EXTRACTION	/INJECTION			RATES	(GPM)		
SCENARIO	SOUTH PLUME	FENCELINE INJECTION	OFF-PROPERTY INJECTION	1	3N	2N	KN	22	SOUTH FIELD PHASE I
B-1	1400/1200	1000	200	250	350	400	150	200	1300
B-2	1400/1200	1000	N/A	250	350	400	150	200	1300
B-3	1400	1000	N/A	N/A	400	400	150	200	1300
B-4	1400	1000	N/A	N/A	400/0	400	150	200	1300
B-5	1400	1000	N/A	400	N/A	400	150	200	1300

Note: N/A Not Applicable

TABLE E-9

OPTIMIZATION WELL EXTRACTION RATE EVALUATION SCENARIOS

	TIMES (FY)							
SCENARIO	SOUTH PLUME	FENCELINE INJECTION	1	3N	2N	KN	22	SOUTH FIELD PHASE I
C-1	1997	1998	1999	N/A	1999	N/A	1998	1999
C-2	1997	1998	1999	N/A	1999	N/A	1998	1999

	EXTRACTION /INJECTION RATES (GPM)							
SCENARIO	SOUTH PLUME	FENCELINE INJECTION	1	3N	2N	KN	22	SOUTH FIELD PHASE I
C-1	1400	1000	400	N/A	400	N/A	200	1300
C-2	1400	1000	250	N/A	250	N/A	200	1300

Note: N/A Not Applicable

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TABLE E-10

ANNUAL MASS RECOVERY RATES OF OPTIMIZATION WELLS IN SCENARIOS B-1 THROUGH B-5

		Mass Removed (lbs)				
Year	Well	Scenario B-1	Scenario B-2	Scenario B-3	Scenario B-4	Scenario B-5
1999-2000	1	125.7	124.9			201.4
	2N	174.4	174.8	178.7	178.7	176.9
	3N	171.7	171.0	196.0	196.0	
	KN	19.1	19.0	19.0	19.0	19.0
	Sub-Total	490.8	489.6	393.6	393.6	397.3
2000-2001	1	72.2	70.4			118.3
	2N	118.8	120.3	127.9	127.9	125.8
	3N	103.2	101.5	117.3	117.3	
	KN	14.0	13.7	13.7	13.7	13.8
	Sub-Total	308.1	305.7	258.9	258.9	257.8
2001-2002	1	52.3	50.3			89.1
	2N	97.1	100.2	106.7	106.7	107.0
	3N	79.7	77.5	90.0		
	KN	12.0	11.6	11.7	11.7	11.7
	Sub-Total	241.0	239.5	208.4	168.7	207.8
2002-2003	1	40.2	38.3			70.1
	2N	82.2	87.3	91.6	92.3	93.5
	3N	63.8	61.8	71.8		
	KN	10.6	10.2	10.4	10.4	10.3
	Sub-Total	196.8	197.5	173.7	102.7	173.9
2003-2004	1	32.1	30.4			56.6
	2N	70.9	77.3	79.7	82.1	82.2
	3N	52.1	50.6	58.6		
	KN	9.5	9.2	9.4	9.5	9.3
	Sub-Total	164.6	167.4	147.6	91.6	148.0

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TABLE E-11

CUMULATIVE MASS REMOVAL RATES OF OPTIMIZATION WELLS IN SCENARIOS B-1 THROUGH B-5

		Mass Removed (lbs)				
Year	Well	Scenario B-1	Scenario B-2	Scenario B-3	Scenario B-4	Scenario B-5
1999-2000	1	125.7	124.9			201.4
	2N	174.4	174.8	178.7	178.7	176.9
	3N	171.7	171.0	196.0	196.0	
	KN	19.1	19.0	19.0	19.0	19.0
	Sub-Total	490.8	489.6	393.6	393.6	397.3
2000-2001	1	197.9	195.2			319.6
	2N	293.1	295.1	306.6	306.6	302.7
	3N	274.9	272.5	313.3	313.3	
	KN	33.1	32.6	32.6	32.6	32.8
	Sub-Total	798.9	795.3	652.5	652.5	655.0
2001-2002	1	250.2	245.5			408.7
	2N	390.2	395.3	413.3	413.3	409.7
	3N	354.5	349.9	403.3	313.3	
	KN	45.0	44.2	44.3	44.3	44.5
	Sub-Total	1039.8	1034.8	860.8	770.8	862.8
2002-2003	1	290.4	283.8			478.8
	2N	472.4	482.5	504.8	505.5	503.1
	3N	418.3	411.7	475.1	313.3	
	KN	55.6	54.4	54.6	54.7	54.8
	Sub-Total	1236.6	1232.3	1034.5	873.5	1036.6
2003-2004	1	322.4	314.1			535.3
	2N	543.3	559.8	584.5	587.6	585.3
	3N	470.4	462.2	533.6	313.3	
	KN	65.1	63.6	64.0	64.2	64.0
	Sub-Total	1401.1	1399.7	1182.0	965.0	1184.6

TABLE E-12

ANNUAL MASS RECOVERY RATES OF OPTIMIZATION WELLS IN SCENARIOS C-1 AND C-2

Year	Mass Removed (lbs)			
	Scenario C-1		Scenario C-2	
	Well 1	Well 2N	Well 1	Well 2N
1999-2000	292.7	293.2	190.0	188.7
2000-2001	185.0	206.2	130.9	139.8
2001-2002	145.1	179.4	106.8	123.0
2002-2003	118.2	160.5	89.4	110.9
2003-2004	98.0	144.1	75.7	100.3

TABLE E-13

CUMULATIVE MASS RECOVERY RATES OF OPTIMIZATION WELLS IN SCENARIOS C-1 AND C-2

	Mass Removed (lbs)			
	Scenario C-1		Scenario C-2	
Year	Well 1	Well 2N	Well 1	Well 2N
1999-2000	292.7	293.2	190.0	188.7
2000-2001	477.7	499.4	320.9	328.6
2001-2002	622.8	678.9	427.7	451.5
2002-2003	741.0	839.4	517.1	562.5
2003-2004	839.0	983.5	592.8	662.8

TABLE E-14

ESTIMATED OUTFALL CONDITIONS FOR SCENARIO C-1

Single Header in South Plume

Year	Total Water Pumped (gpm)	Treatment Capacity (gpm)	Water to Treatment (gpm)	Conc. to Treatment (ppb)	Water Not Treated (gpm)	Conc. not Treated (ppb)	Injected Water (gpm)	Conc. of Injected Water (ppb)	Water Discharged (gpm)	Conc. of Discharge (ppb)
1997	1400	400	400	28.8	1000	28.8	0	N/A	1400	22.0
1998	1600	2000	1600	58.0	0	0.0	1000	5	600	13.3
1999	3700	2000	2000	114.1	1700	41.6	1000	5	2700	28.0
2000	3700	2000	2000	114.3	1700	35.0	1000	5	2700	23.9
2001	3700	2000	2000	118.3	1700	30.3	1000	5	2700	20.9
2002	3700	2000	2000	119.2	1700	26.8	1000	5	2700	18.7
2003	3700	2000	2000	109.9	1700	23.6	1000	5	2700	16.7

Double Headers in South Plume

Year	Total Water Pumped (gpm)	Treatment Capacity (gpm)	Water to Treatment (gpm)	Conc. to Treatment (ppb)	Water Not Treated (gpm)	Conc. not Treated (ppb)	Injected Water (gpm)	Conc. of Injected Water (ppb)	Water Discharged (gpm)	Conc. of Discharge (ppb)
1997	1400	400	400	28.8	1000	28.8	0	N/A	1400	22.0
1998	1600	2000	1600	58.0	0	0.0	1000	5	600	13.3
1999	3700	2000	2000	103.5	1700	31.2	1000	5	2700	21.5
2000	3700	2000	2000	99.4	1700	28.4	1000	5	2700	19.7
2001	3700	2000	2000	96.7	1700	27.9	1000	5	2700	19.4
2002	3700	2000	2000	100.4	1700	24.3	1000	5	2700	17.2
2003	3700	2000	2000	99.5	1700	21.5	1000	5	2700	15.4

000206

TABLE E-15

ESTIMATED OUTFALL CONDITIONS FOR SCENARIO C-2

Single Header in South Plume

Year	Total Water Pumped (gpm)	Treatment Capacity (gpm)	Water to Treatment (gpm)	Conc. to Treatment (ppb)	Water Not Treated (gpm)	Conc. not Treated (ppb)	Injected Water (gpm)	Conc. of Injected Water (ppb)	Water Discharged (gpm)	Conc. of Discharge (ppb)
1997	1400	400	400	28.8	1000	28.8	0	N/A	1400	22.0
1998	1600	2000	1600	58.0	0	0.0	1000	5	600	13.3
1999	3400	2000	2000	114.8	1400	42.5	1000	5	2400	26.9
2000	3400	2000	2000	116.1	1400	38.8	1000	5	2400	24.7
2001	3400	2000	2000	120.5	1400	34.3	1000	5	2400	22.1
2002	3400	2000	2000	121.7	1400	30.8	1000	5	2400	20.1
2003	3400	2000	2000	122.1	1400	27.3	1000	5	2400	18.0

Double Headers in South Plume

Year	Total Water Pumped (gpm)	Treatment Capacity (gpm)	Water to Treatment (gpm)	Conc. to Treatment (ppb)	Water Not Treated (gpm)	Conc. not Treated (ppb)	Injected Water (gpm)	Conc. of Injected Water (ppb)	Water Discharged (gpm)	Conc. of Discharge (ppb)
1997	1400	400	400	28.8	1000	28.8	0	N/A	1400	22.0
1998	1600	2000	1600	58.0	0	0.0	1000	5	600	13.3
1999	3400	2000	2000	104.2	1400	33.6	1000	5	2400	21.7
2000	3400	2000	2000	106.4	1400	30.6	1000	5	2400	19.9
2001	3400	2000	2000	111.9	1400	27.8	1000	5	2400	18.3
2002	3400	2000	2000	114.0	1400	25.4	1000	5	2400	16.9
2003	3400	2000	2000	114.9	1400	23.2	1000	5	2400	15.6

TABLE E-16

MASS OF URANIUM REMOVED BY MODULE FOR SCENARIO C-1

Year	System I	System II	System III	System IV	System IV-Opt	Injected Mass	Yearly
1997	N/A	N/A	N/A	176.6	N/A	0.0	176.6
1998	N/A	209.3	N/A	196.5	N/A	21.9	383.9
1999	N/A	906.9	N/A	184.2	216.0	21.9	1285.2
2000	N/A	923.9	N/A	161.5	175.2	21.9	1238.8
2001	N/A	969.0	N/A	142.5	149.3	21.9	1238.9
2002	N/A	984.8	N/A	128.3	129.4	21.9	1220.5
2003	N/A	907.0	N/A	117.2	112.7	21.9	1115.1

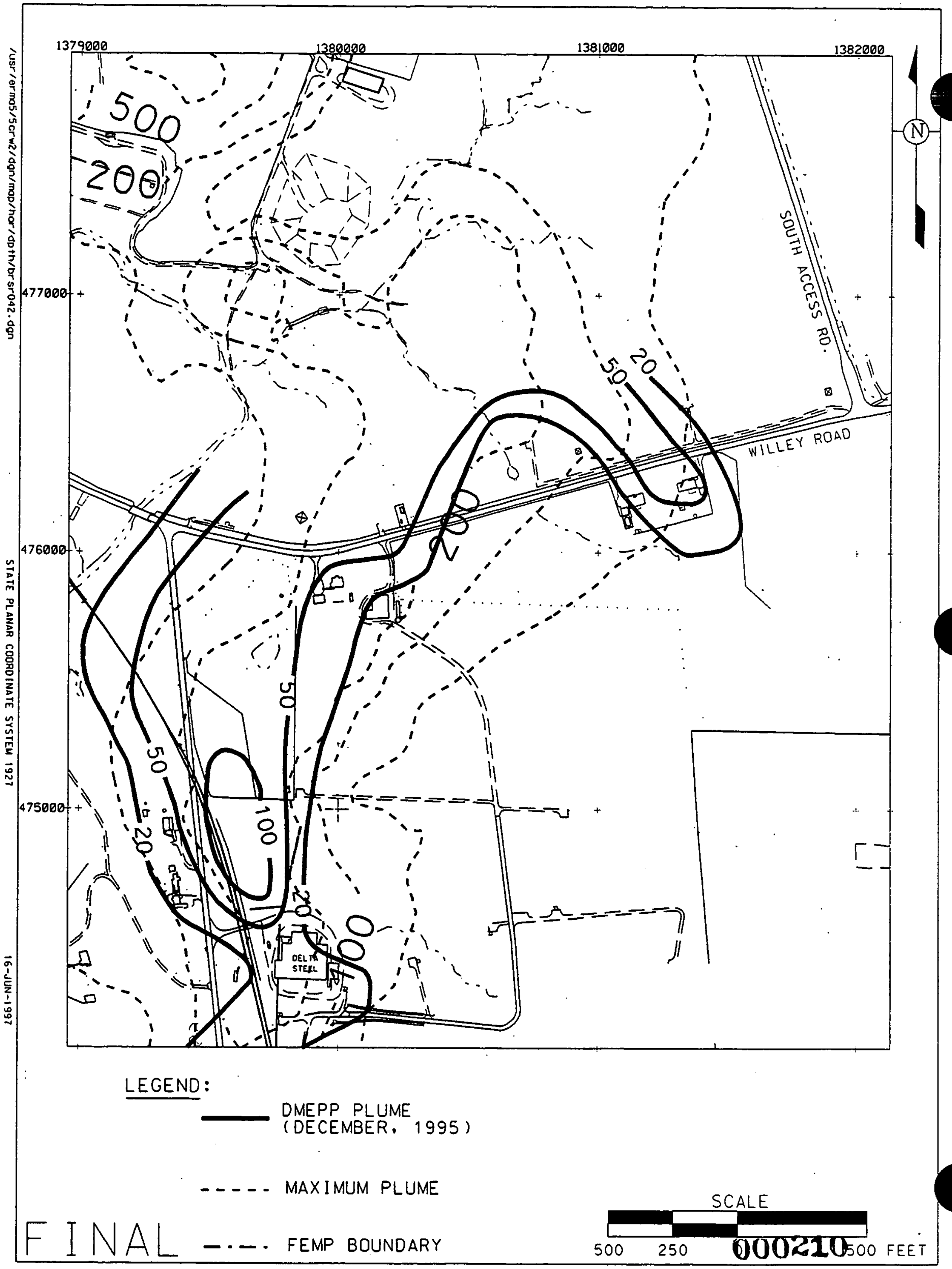
System I = Waste Pit
System II = Production Area
System II = South Field (Phases I and II)
System IV = South Plume (RW-1, RW-2, RW-3, RW-4)
System IV-Opt = Wells 1 & 2N (RW-6 & RW-7)

TABLE E-17

MASS OF URANIUM REMOVED BY MODULE (lbs.) FOR SCENARIO C-2

Year	System I	System II	System III	System IV	System IV-Opt	Injected Mass	Yearly Total
1997	N/A	N/A	N/A	176.6	N/A	0.0	176.6
1998	N/A	209.3	N/A	196.5	N/A	21.9	383.9
1999	N/A	912.1	N/A	206.1	147.6	21.9	1243.9
2000	N/A	931.4	N/A	187.2	135.3	21.9	1232.0
2001	N/A	979.7	N/A	170.4	114.9	21.9	1243.1
2002	N/A	998.0	N/A	155.9	100.2	21.9	1232.1
2003	N/A	1003.8	N/A	143.8	88.0	21.9	1213.8

System I = Waste Pit
System II = Production Area
System II = South Field (Phases I and II)
System IV = South Plume (RW-1, RW-2, RW-3, RW-4)
[illegible]m IV-Opt = Wells 1 & 2N (RW-6 & RW-7)



000210

FIGURE E-1. COMPARISON BETWEEN THE MAXIMUM AND DMEPP URANIUM PLUMES

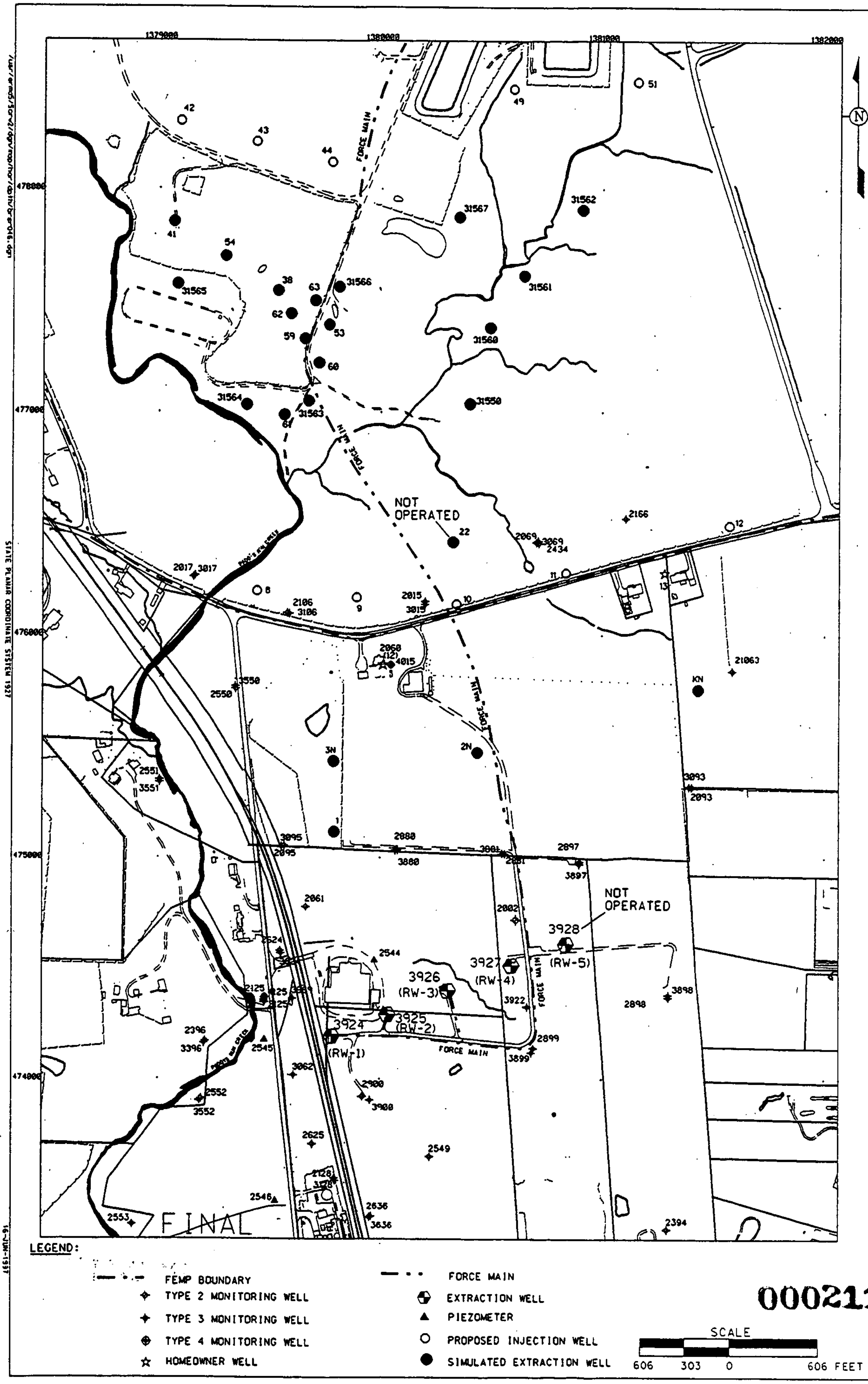


FIGURE E-2. WELL LOCATIONS FOR SCENARIO I

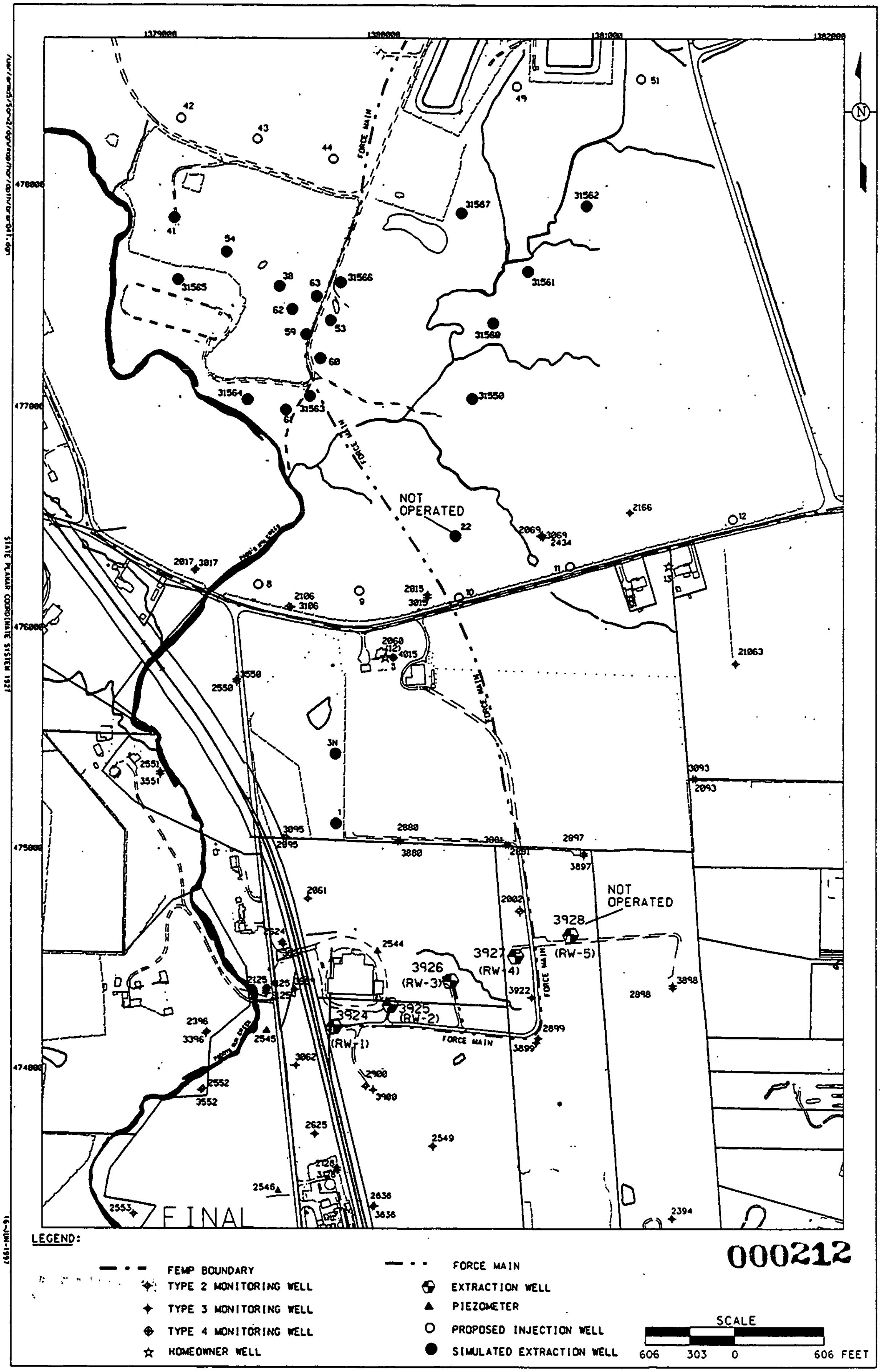
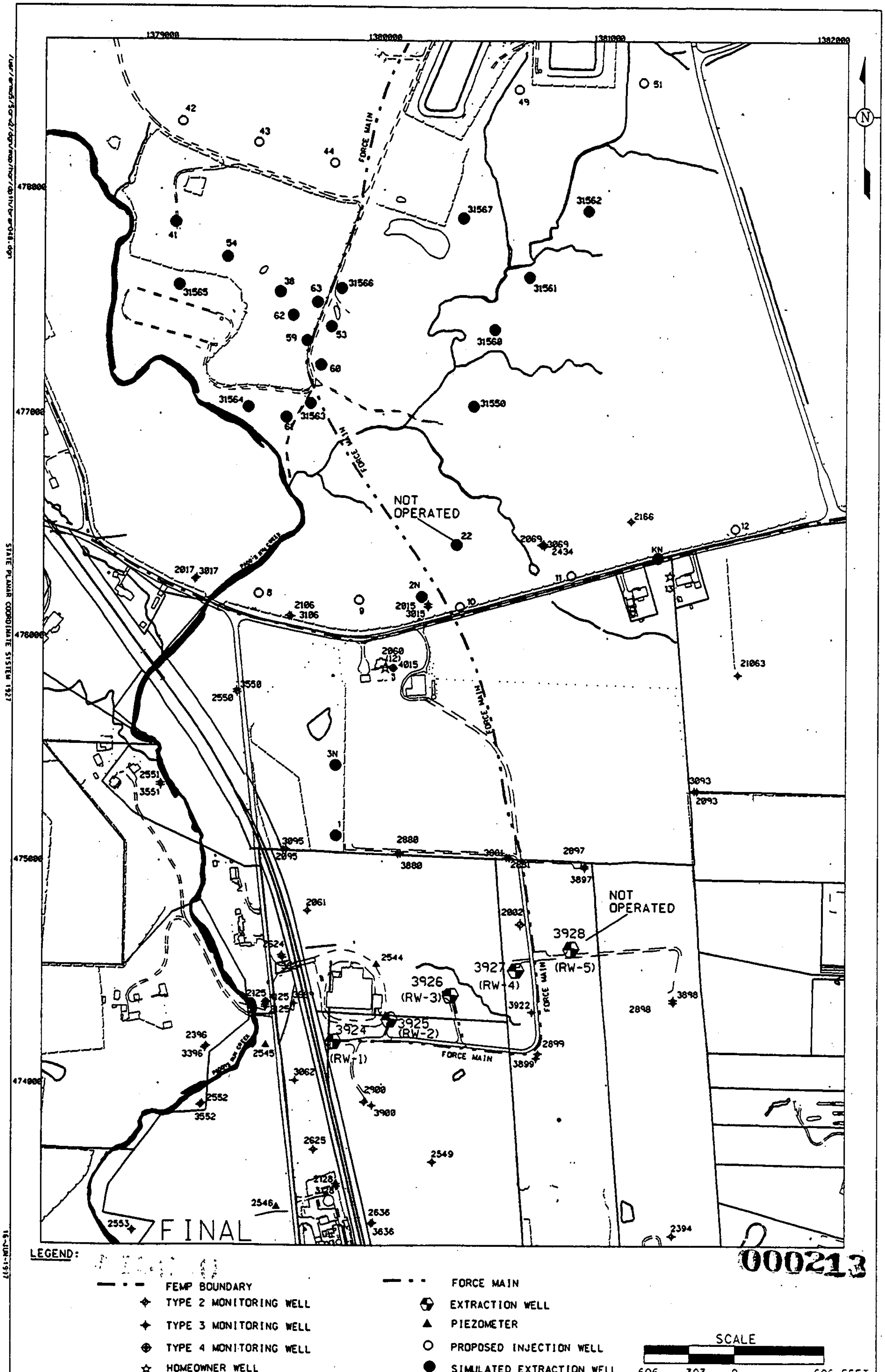


FIGURE E-3. WELL LOCATIONS FOR SCENARIO II



000213

FIGURE E-4. WELL LOCATIONS FOR SCENARIO III

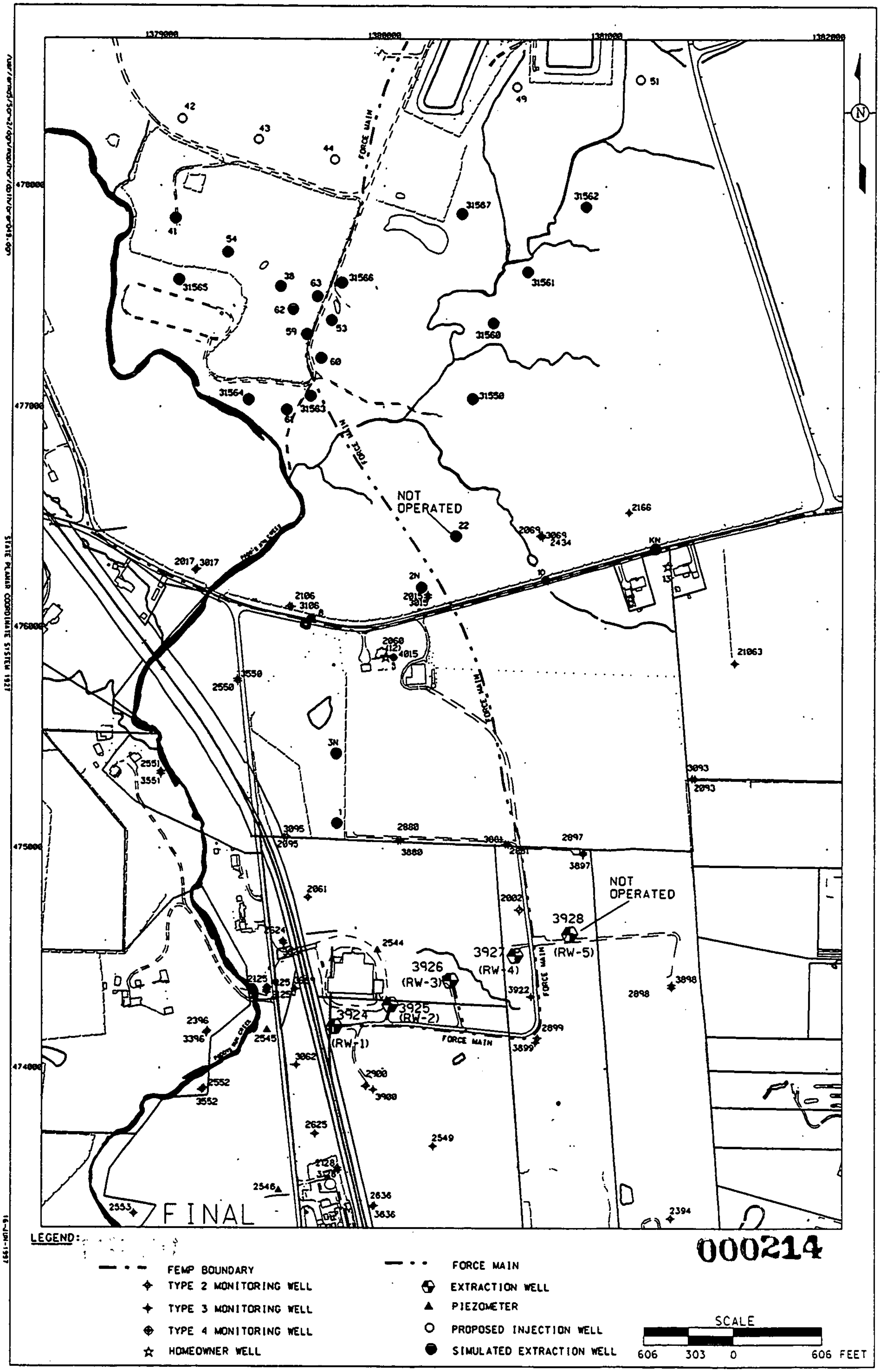


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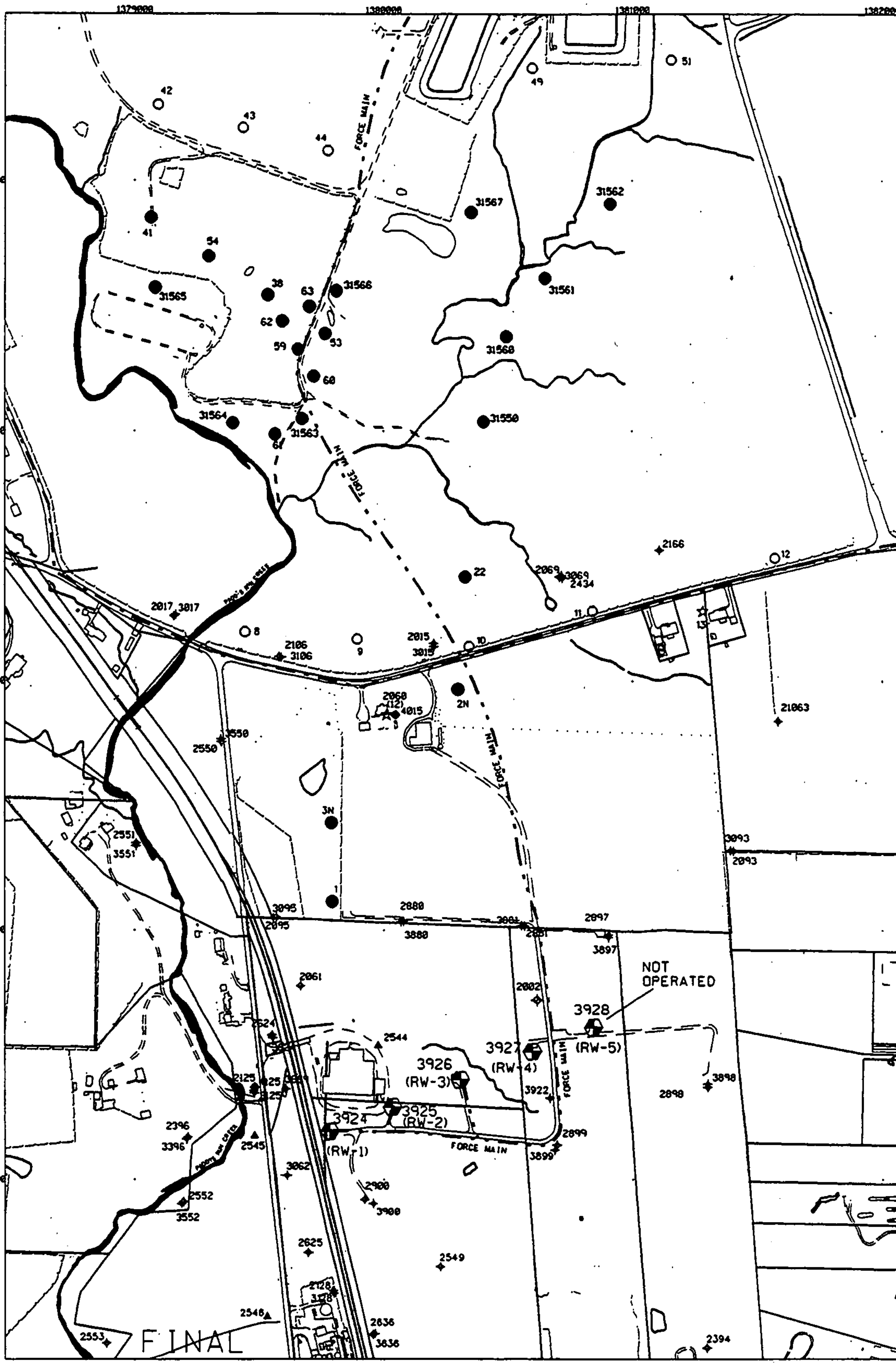
FIGURE E-5. WELL LOCATIONS FOR SCENARIO IV



LEGEND:

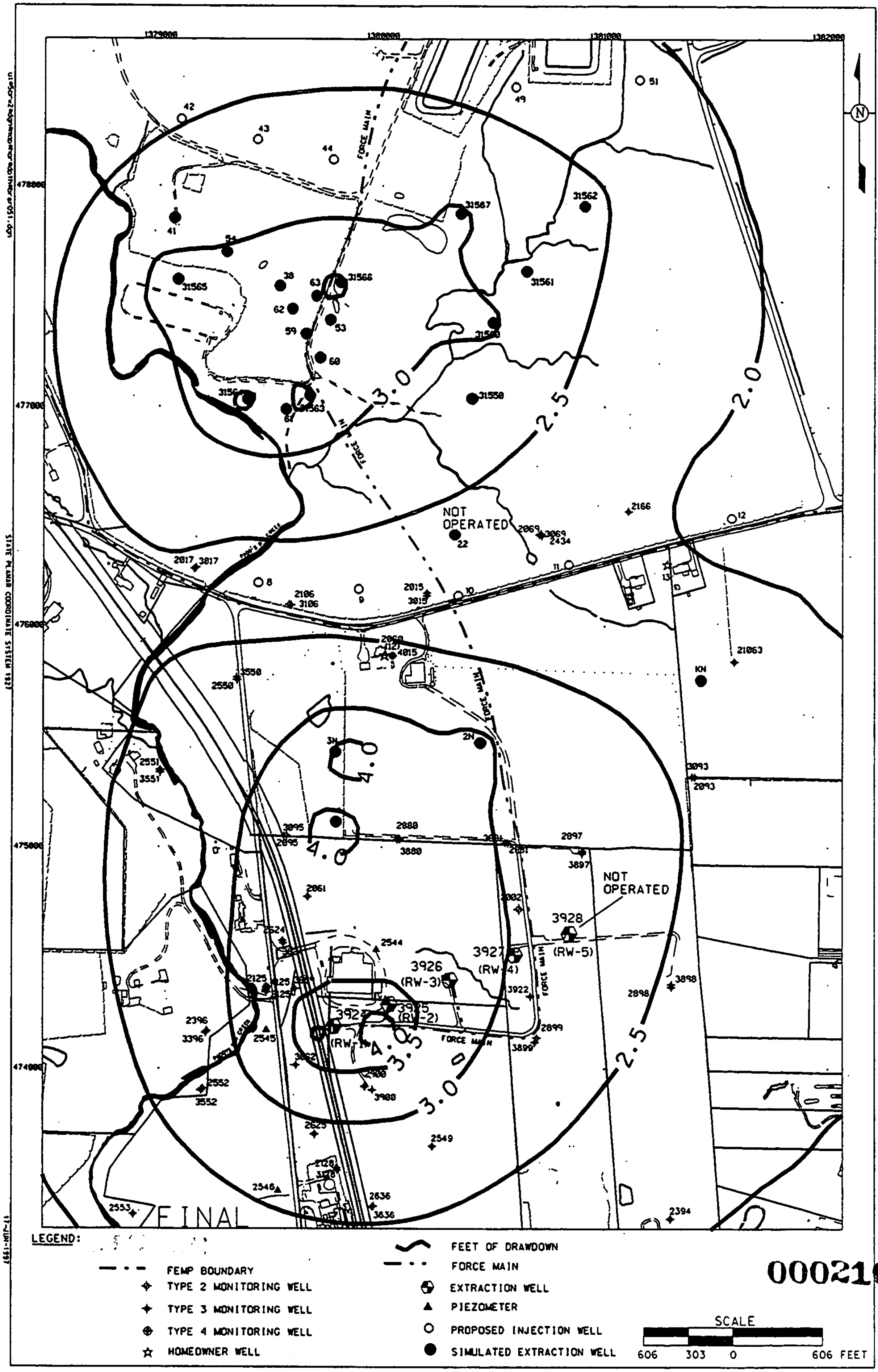
- FEMP BOUNDARY
- TYPE 2 MONITORING WELL
- TYPE 3 MONITORING WELL
- TYPE 4 MONITORING WELL
- HOMEOWNER WELL
- FORCE MAIN
- EXTRACTION WELL
- PIEZOMETER
- PROPOSED INJECTION WELL
- SIMULATED EXTRACTION WELL

SCALE

606 303 0 606 FEET

000215

FIGURE E-6. WELL LOCATIONS FOR SCENARIO V



000216

FIGURE E-7. DRAWDOWN AT 1999 - SCENARIO I

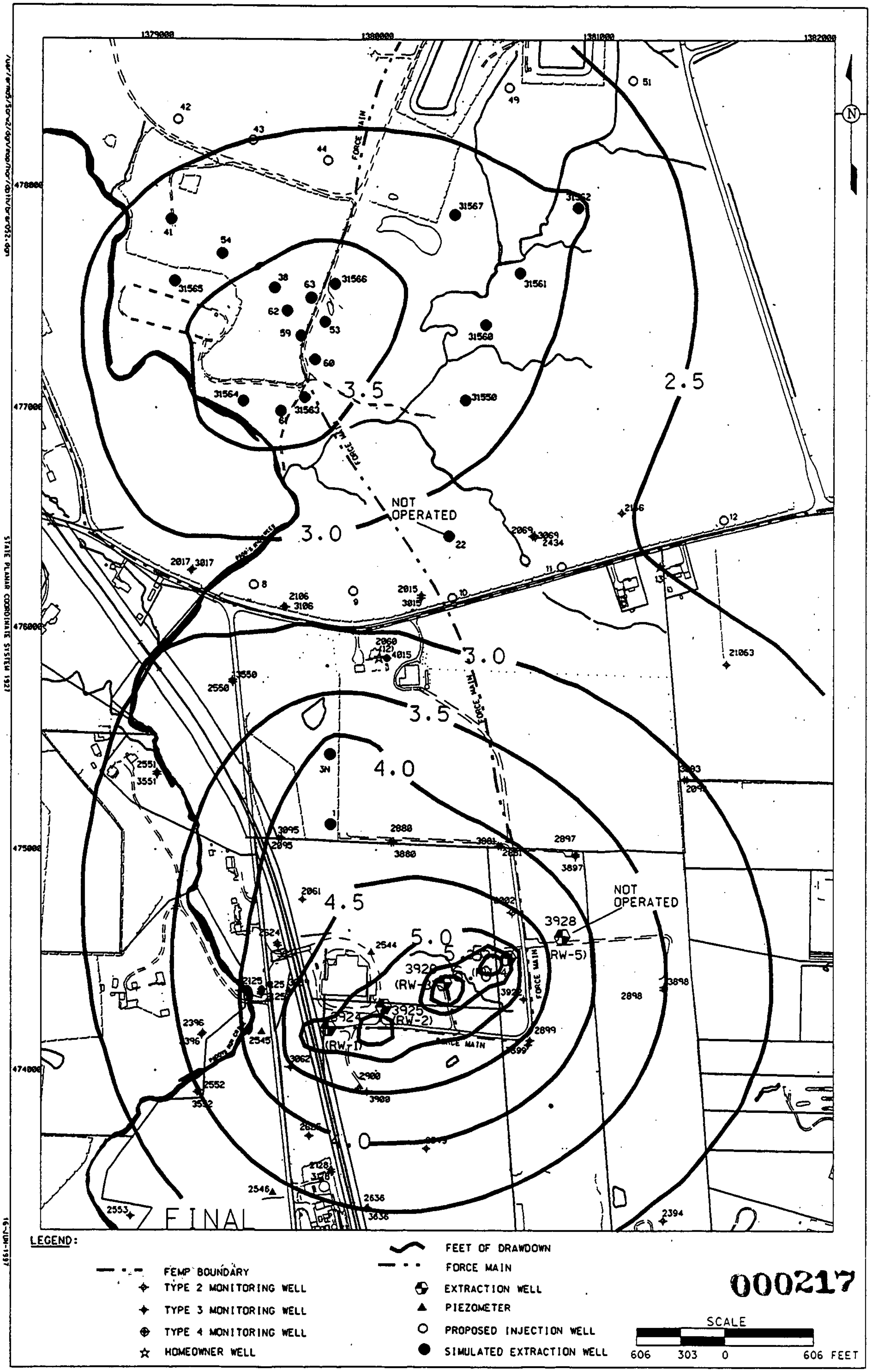
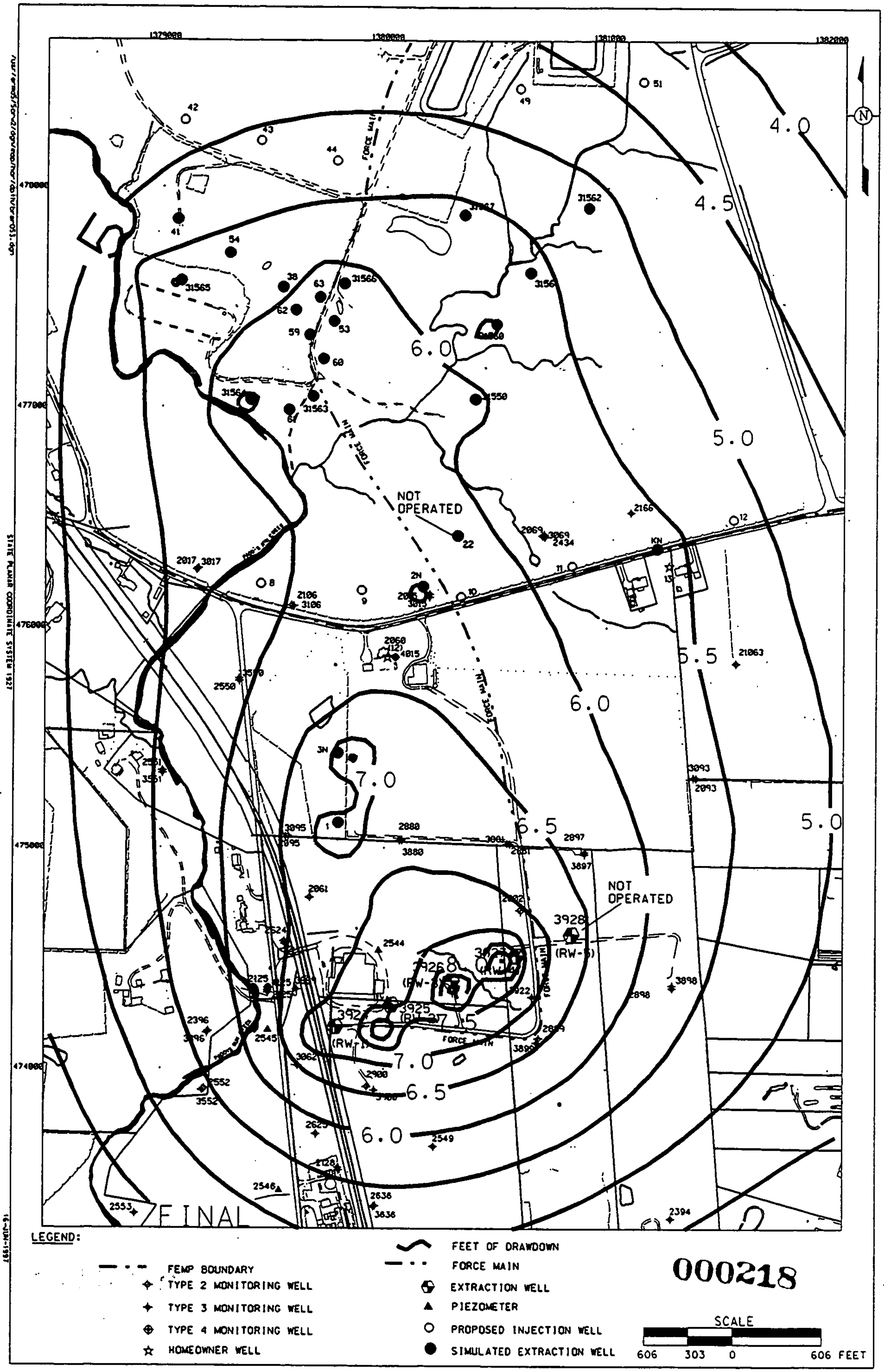
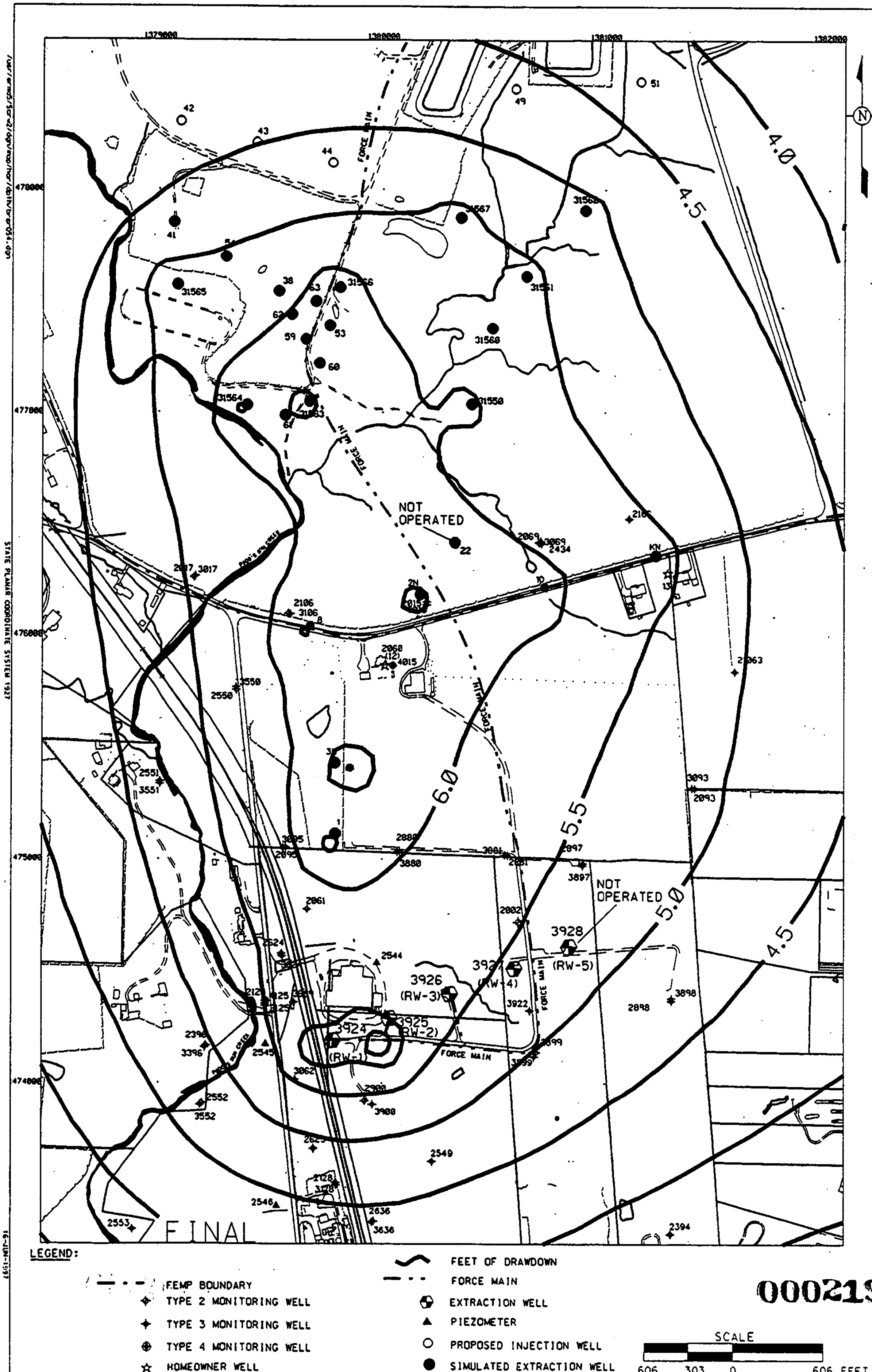


FIGURE E-8. DRAWDOWN AT 1999 - SCENARIO II



000218

FIGURE E-9. DRAWDOWN AT 1999 - SCENARIO III



000219

FIGURE E-10. DRAWDOWN AT 2003 - SCENARIO IV

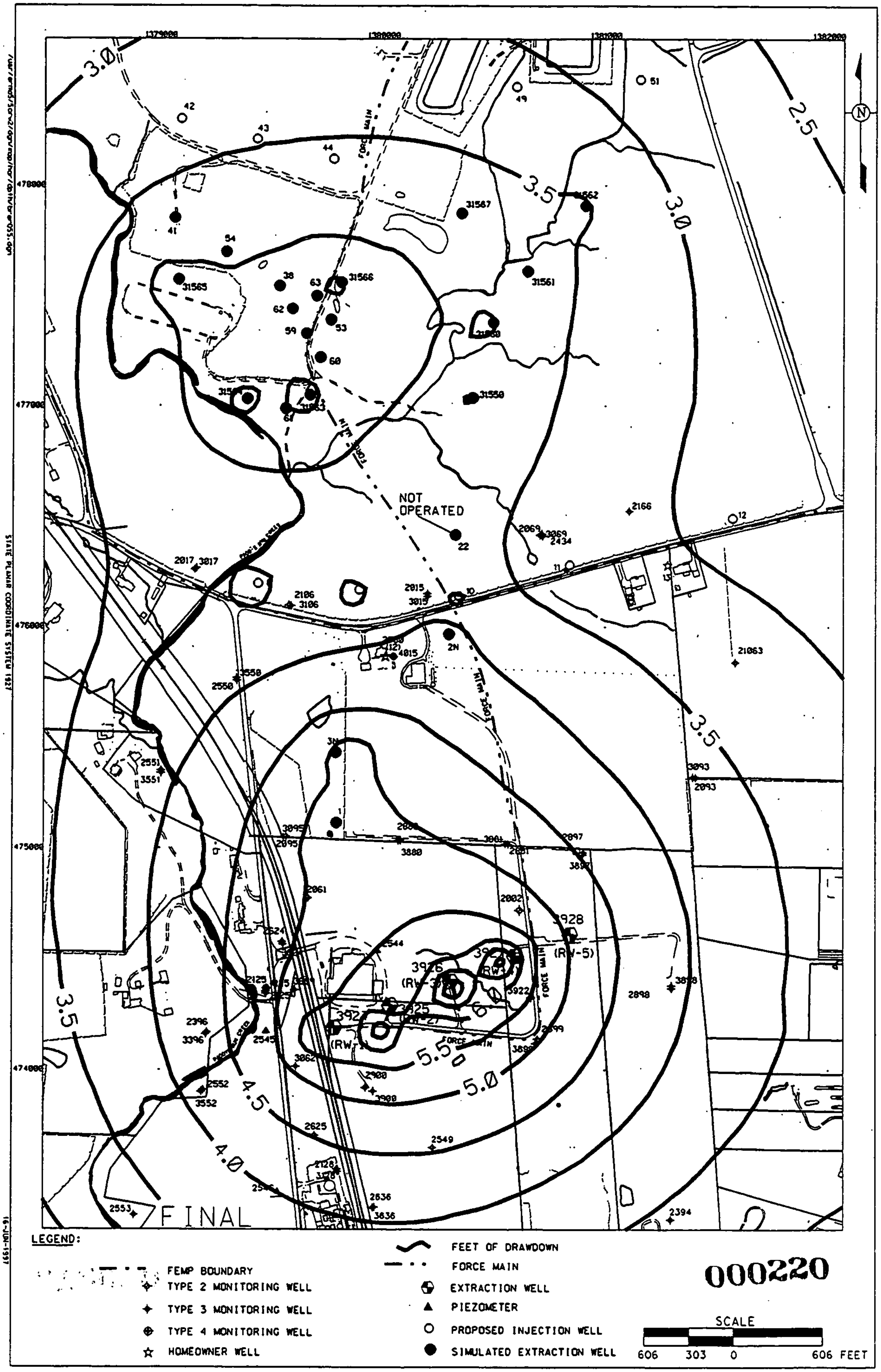
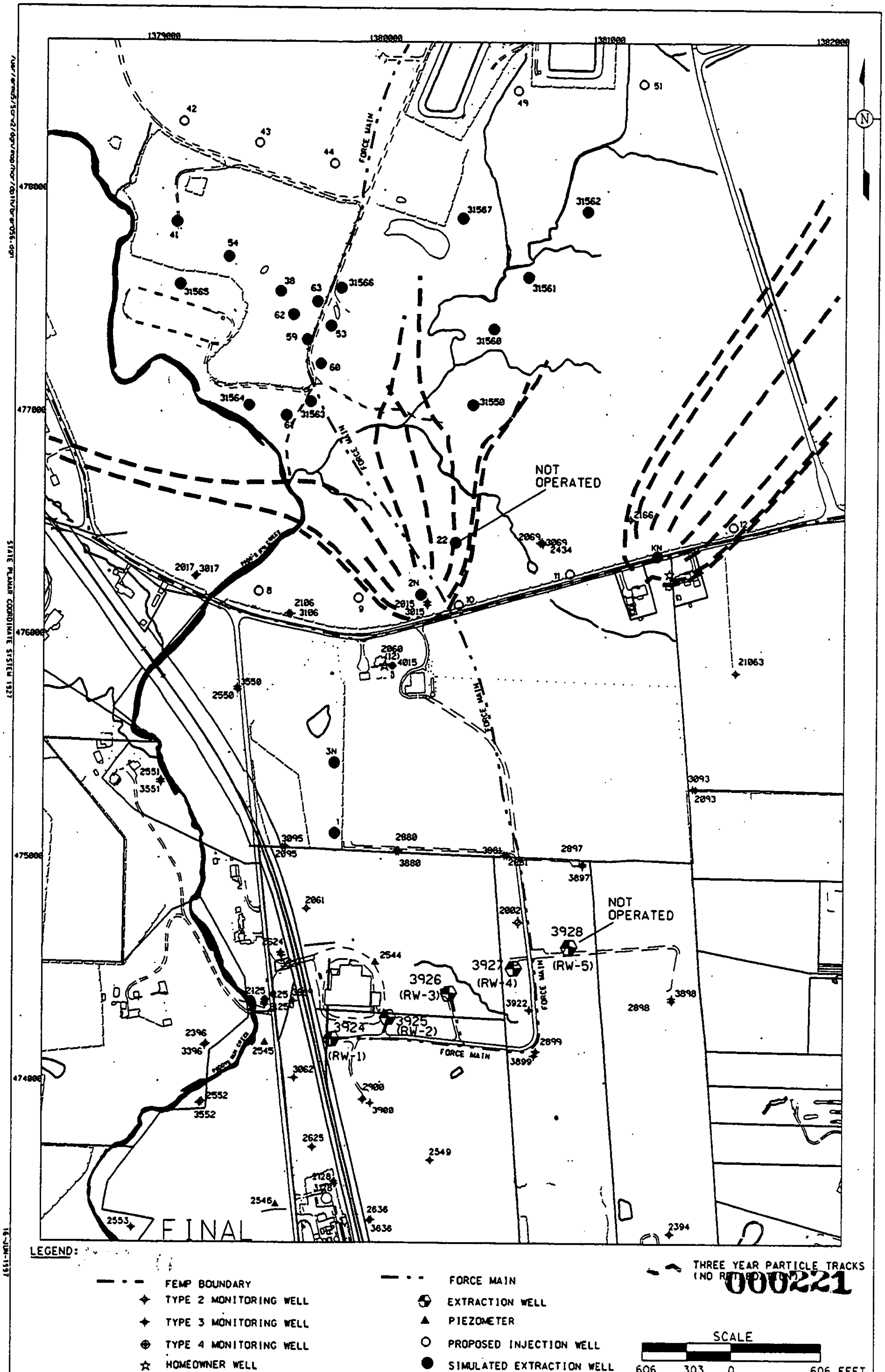


FIGURE E-11. DRAWDOWN AT 2003 - SCENARIO V



000221

FIGURE E-12. CAPTURE ZONES OF POTENTIAL FENCELINE EXTRACTION WELLS - SCENARIO III

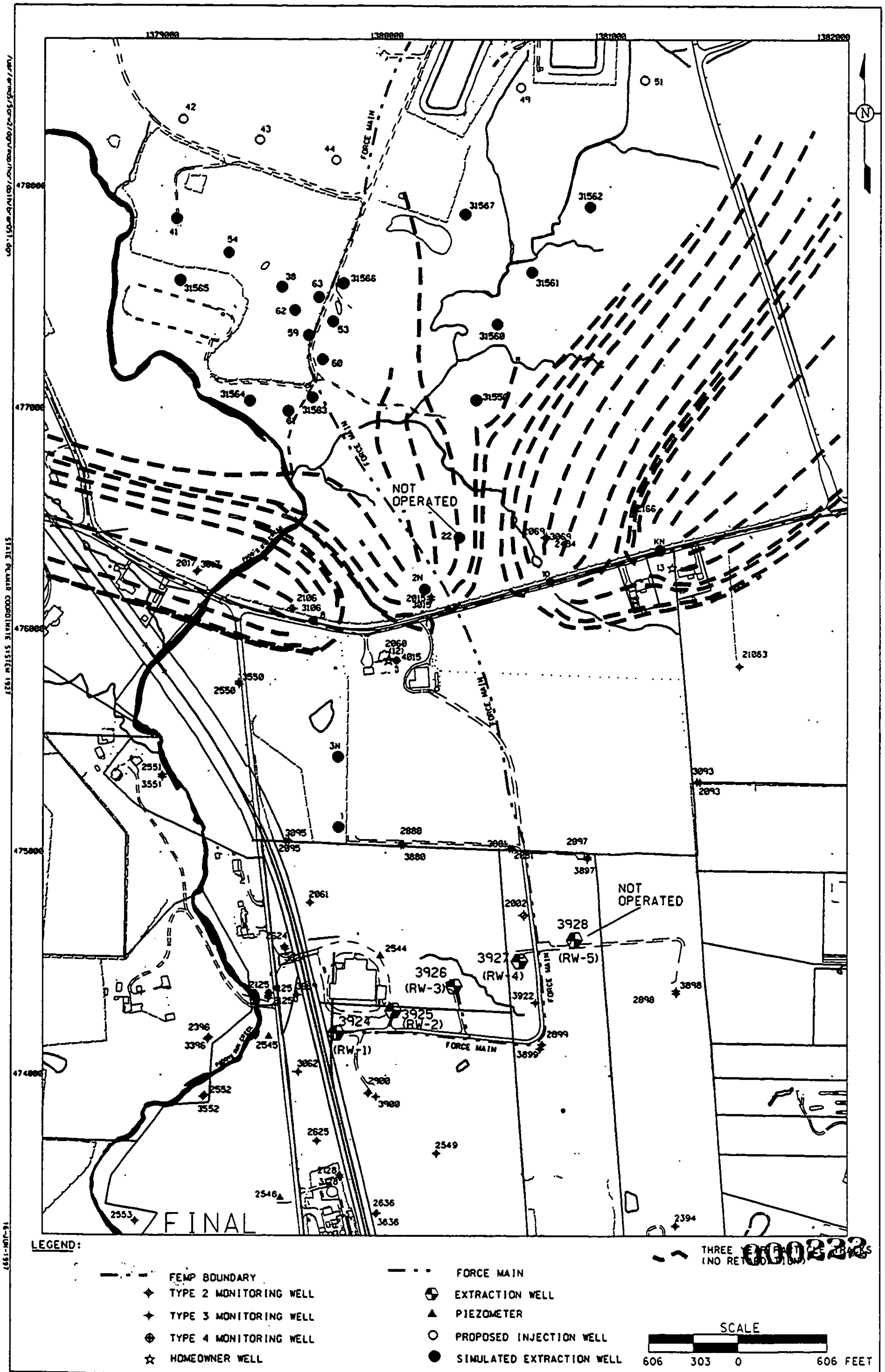
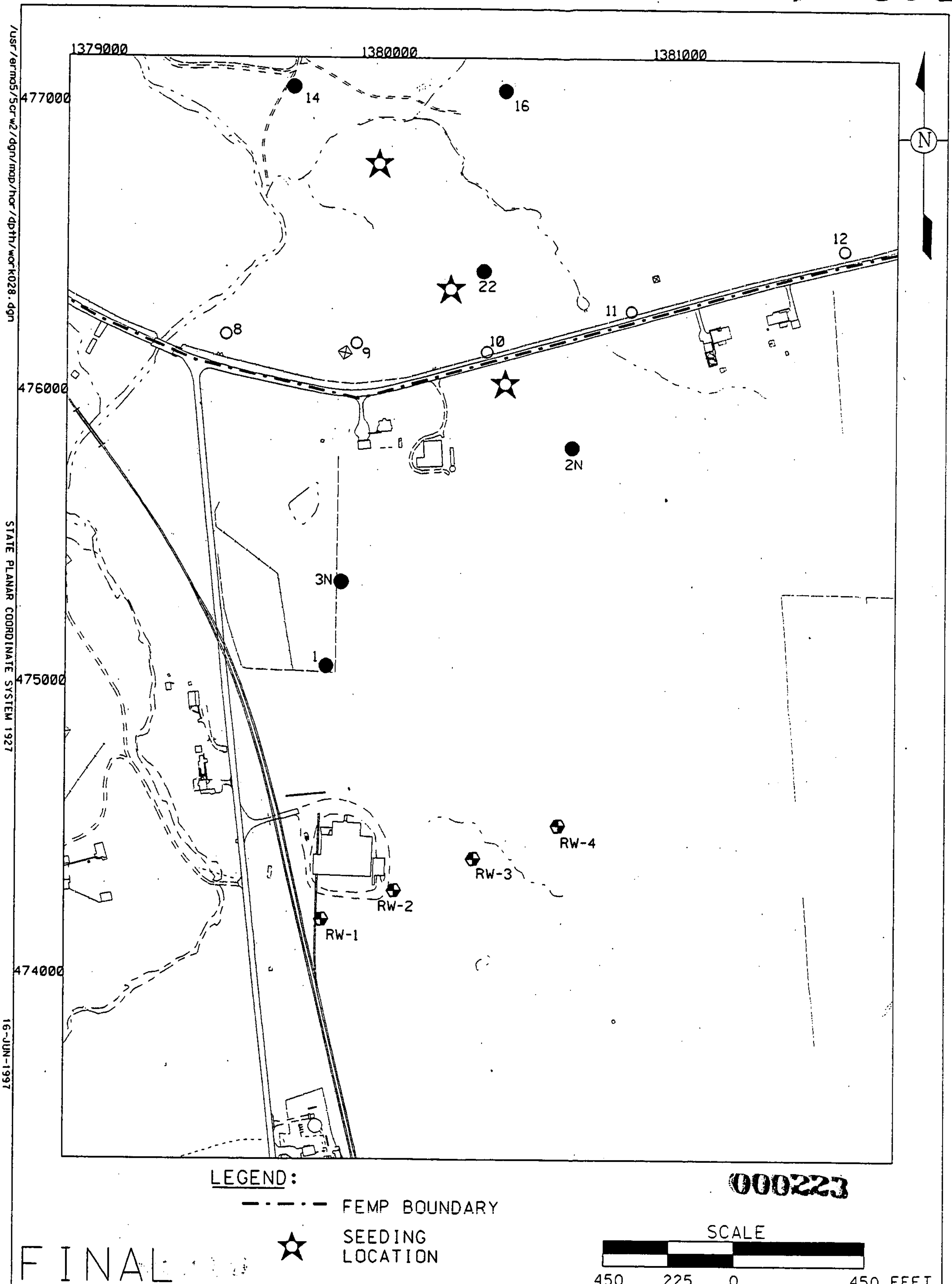


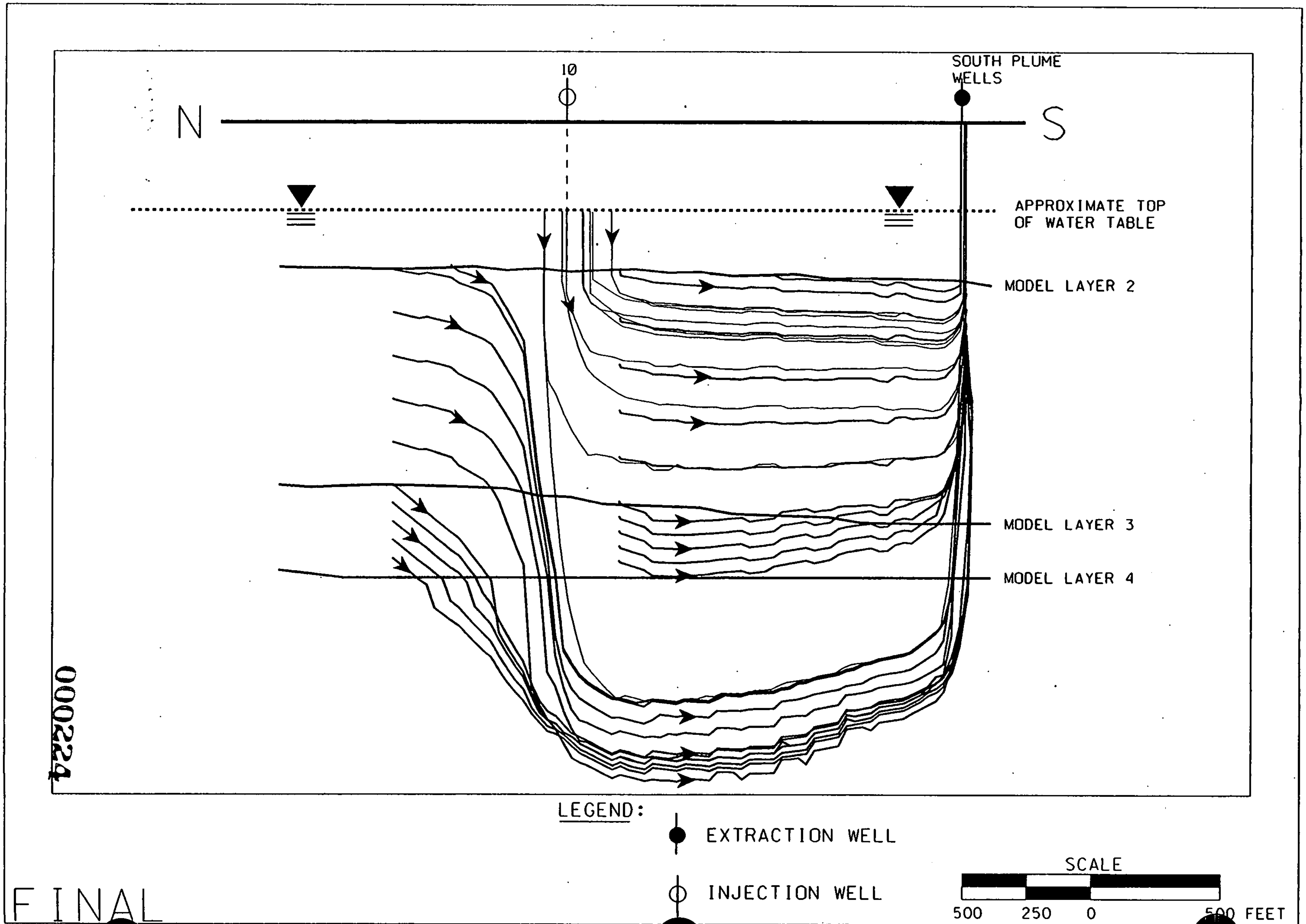
FIGURE E-13. CAPTURE ZONES OF POTENTIAL FENCELINE EXTRACTION WELLS - SCENARIO IV



FINAL

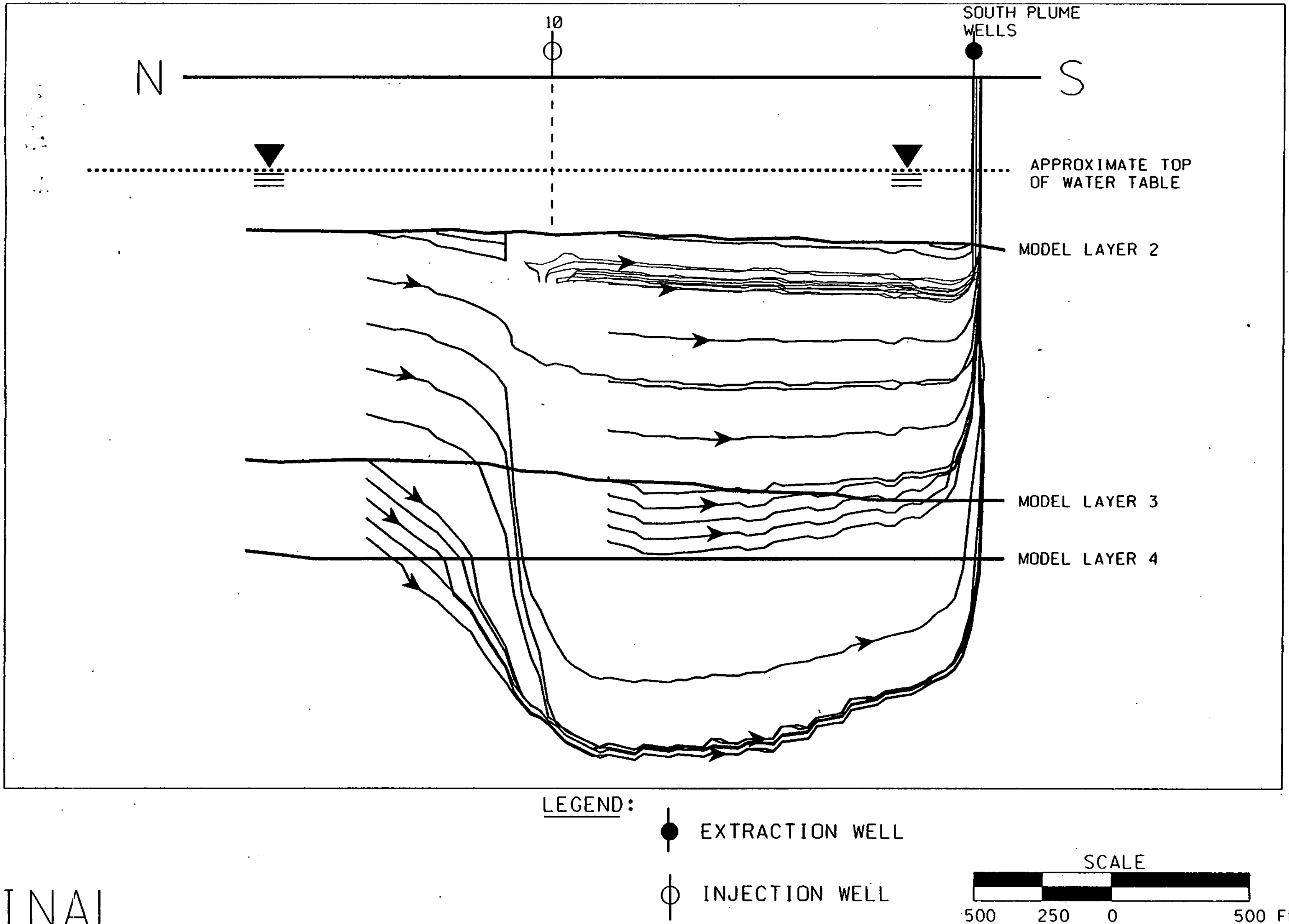
000223

FIGURE E-14. LOCATION MAP FOR VERTICAL CROSS SECTIONS PARTICLE SEEDING POINTS



/usr/erma5/5cr[illegible]map/hor/dpth/work021.dgn 16-JUN-1997
STATE PLANAR C[illegible]TE SYSTEM 1927

F[illegible]E E-15. SIMULATED 10-YEAR CROSS-SECTI[illegible]
PARTICLE TRACKS - SCENARIO 1



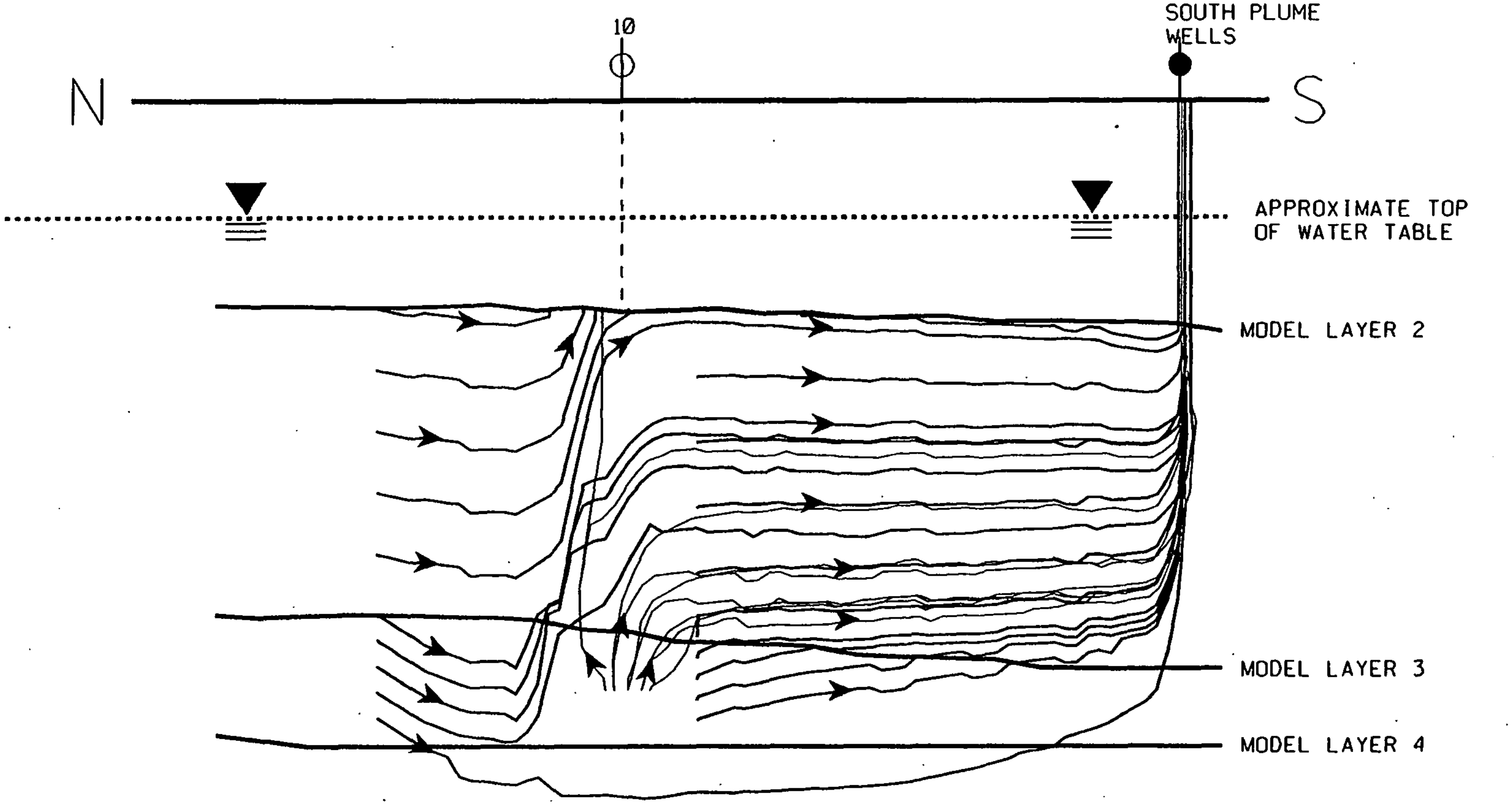
000225

FINAL

/usr/erma5/5crw2/dgn/map/hor/dpth/work022.dgn 16-JUN-1997
STATE PLANAR COORDINATE SYSTEM 1927

FIGURE E-16. SIMULATED 10-YEAR CROSS-SECTIONAL PARTICLE TRACKS - SCENARIO 2

8651



LEGEND:

EXTRACTION WELL

INJECTION WELL

SCALE

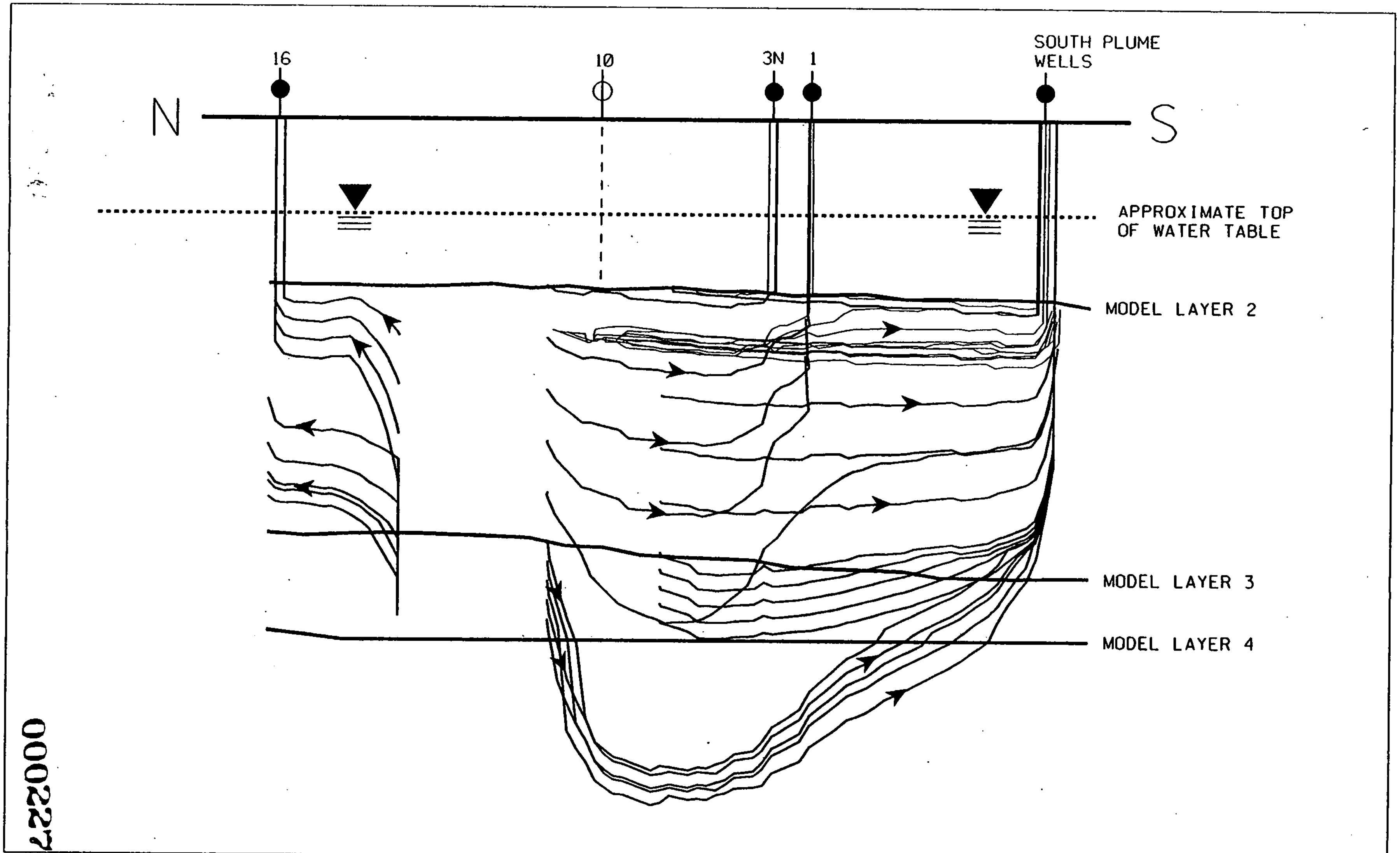
500 250 0 500 FEET

FINAL

/usr/erma5/5cr... map/hor/dpth/work023.dgn 16-JUN-1997
STATE PLANAR C... TE SYSTEM 1927

FI...E E-17. SIMULATED 10-YEAR CROSS-SECTI...
PARTICLE TRACKS - SCENARIO 3

000226



LEGEND:

EXTRACTION WELL

INJECTION WELL

SCALE

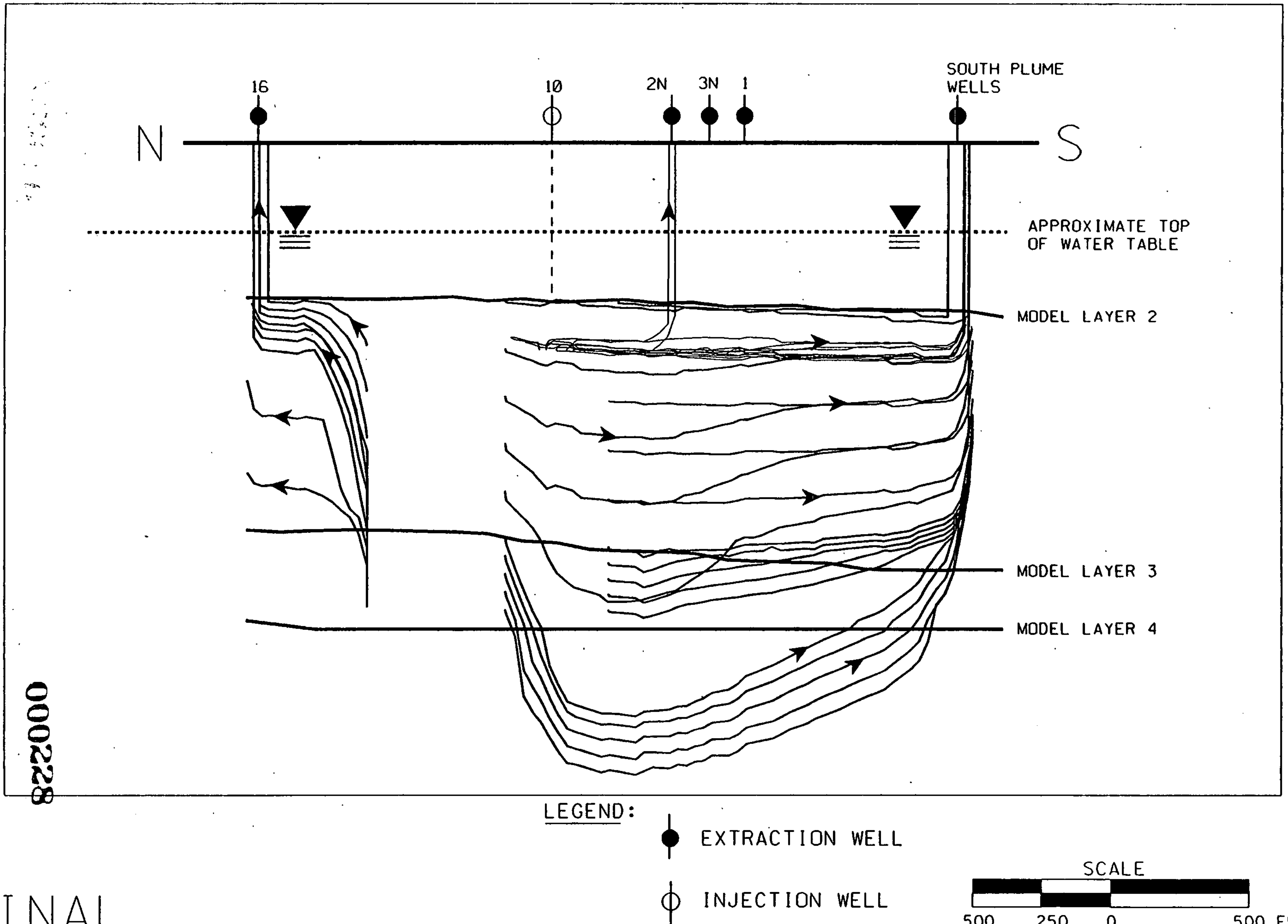
500 250 0 500 FEET

FINAL

/usr/ermo5/5crw2/dgn/map/hor/dpth/work020.dgn 16-JUN-1997
STATE PLANAR COORDINATE SYSTEM 1927

FIGURE E-18. SIMULATED 10-YEAR CROSS-SECTIONAL
PARTICLE TRACKS - SCENARIO 4

8651



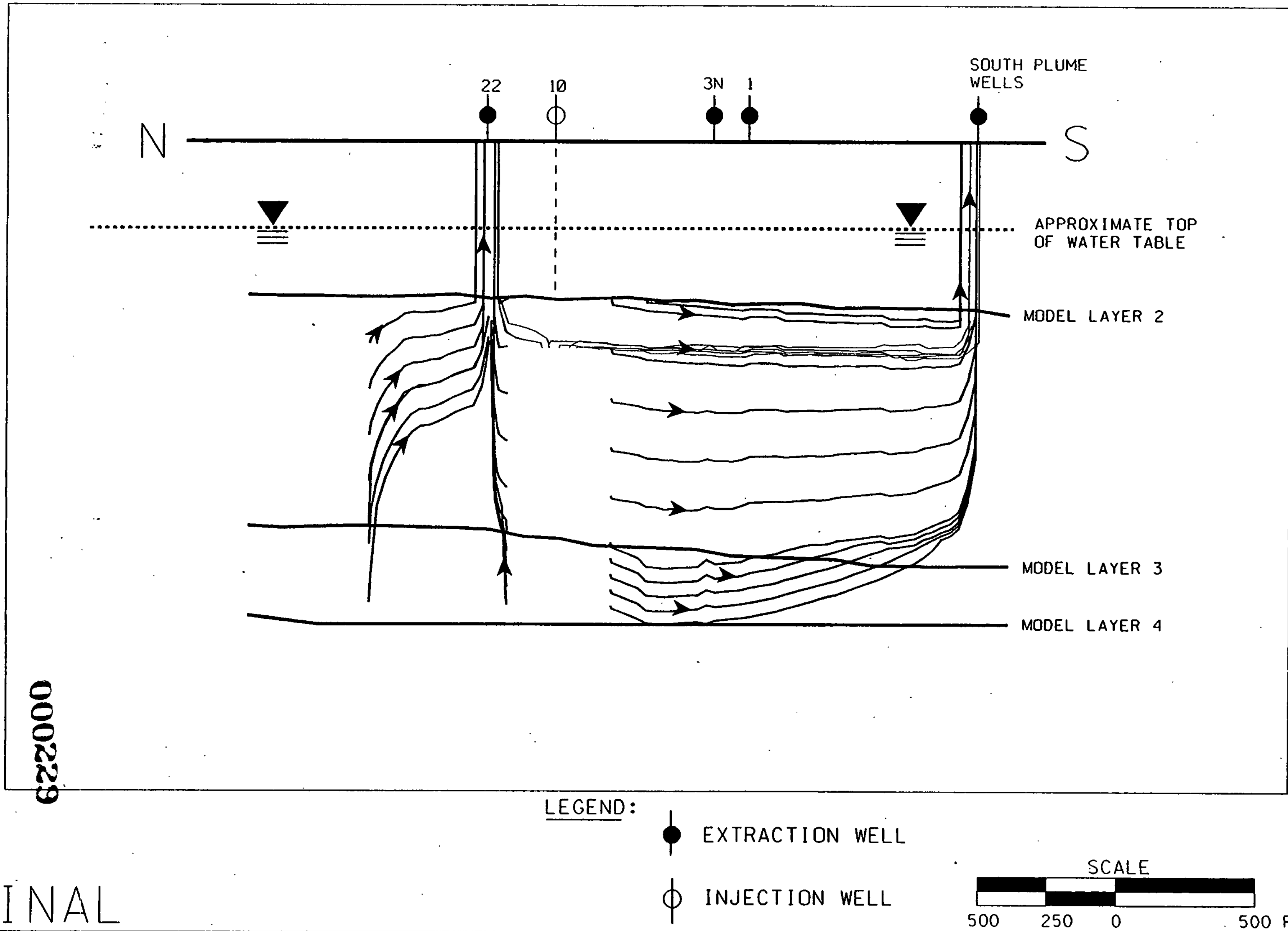
000228

FINAL

u:*5crw2*dgn*m... dpth*work025.dgn
STATE PLANAR C... TE SYSTEM 1927

17-JUN-1997

FI... E E-19. SIMULATED 10-YEAR CROSS-SECTIO... PARTICLE TRACKS - SCENARIO 5



000229

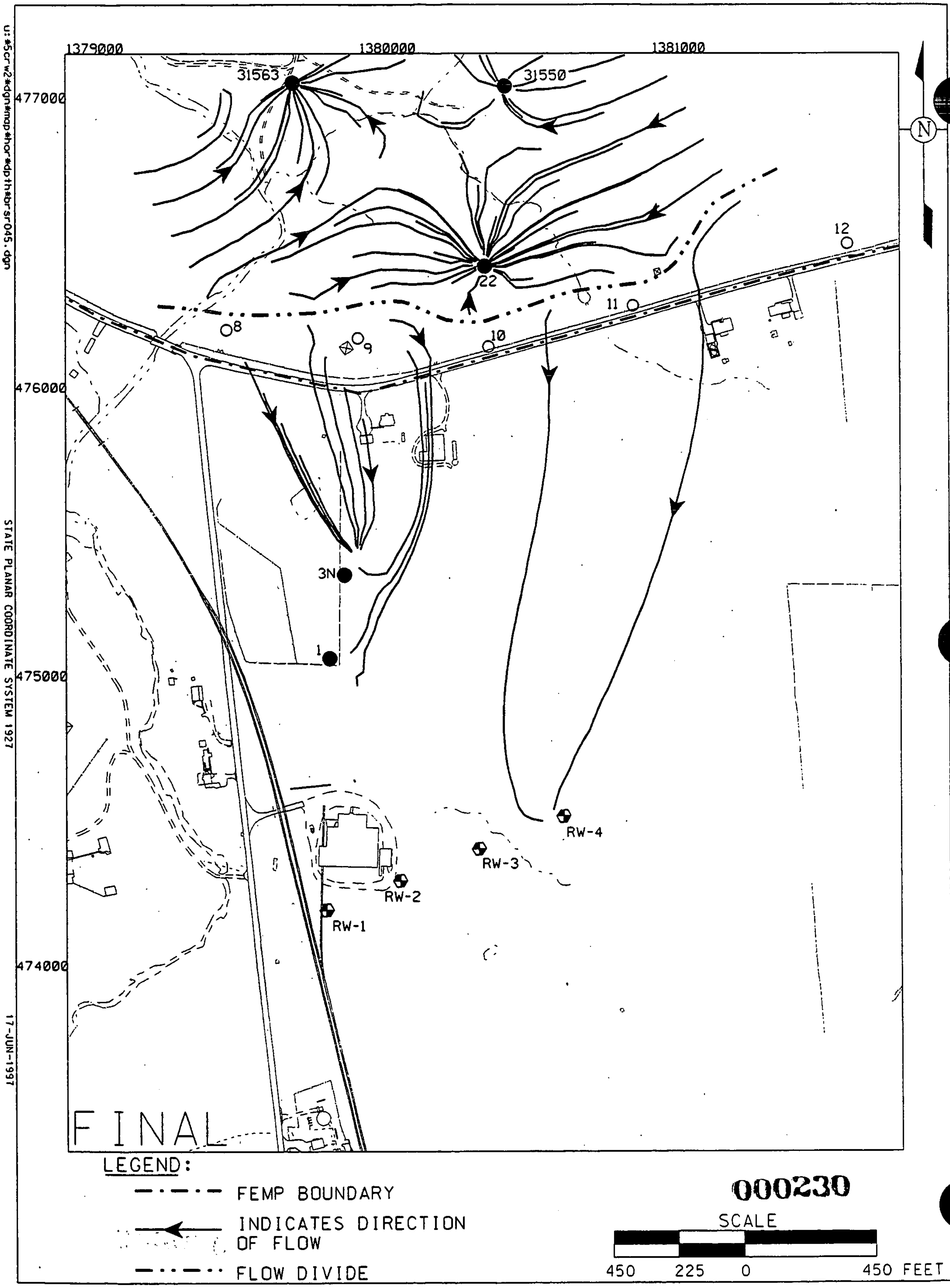
FINAL

u:*5crw2*dgn*map*hor*dpth*work024.dgn
STATE PLANAR COORDINATE SYSTEM 1927

17-JUN-1997

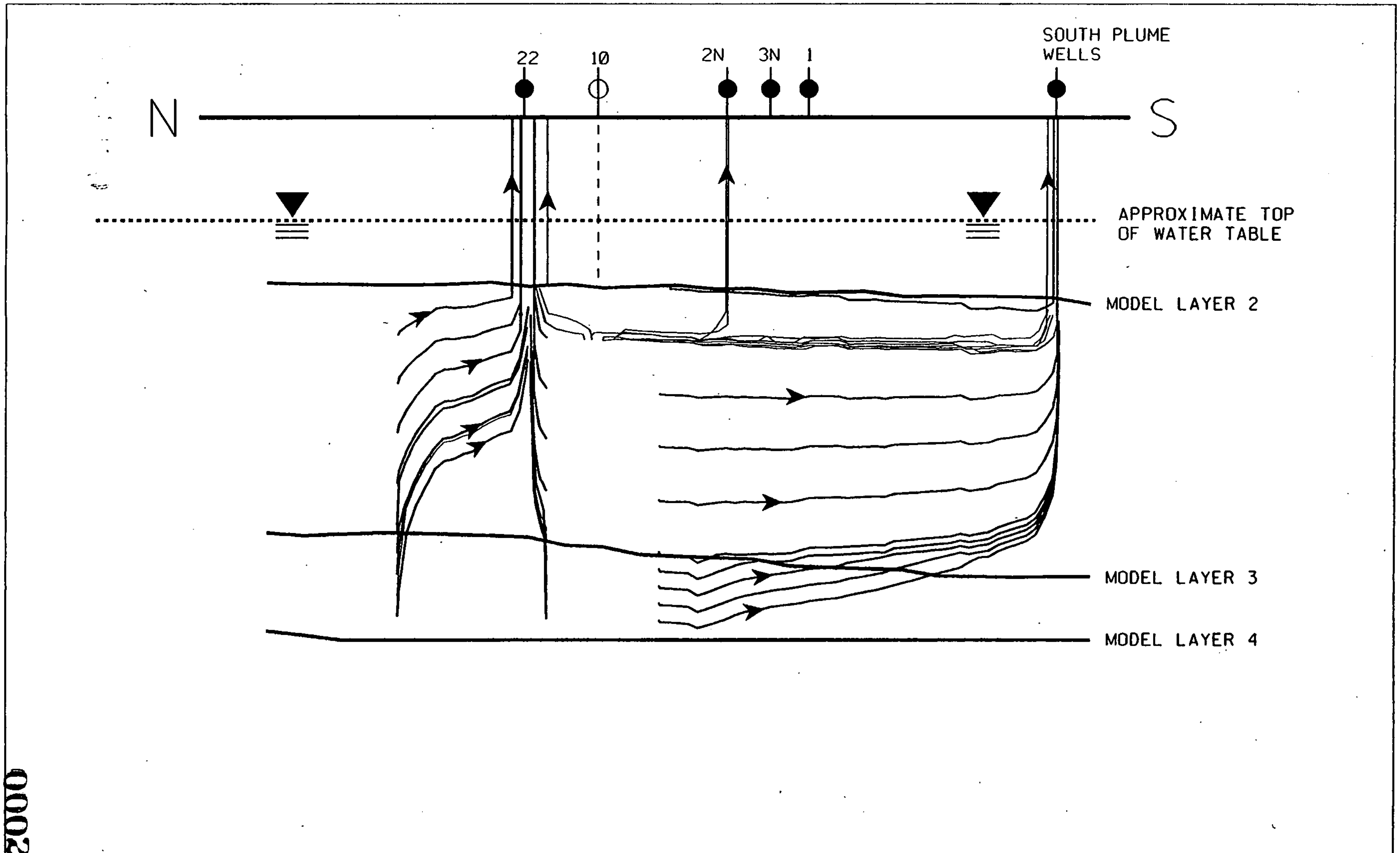
FIGURE E-20. SIMULATED 10-YEAR CROSS-SECTIONAL PARTICLE TRACKS - SCENARIO 6

851



000230

FIGURE E-21. SIMULATED 10-YEAR AREAL PARTICLE TRACKS AND FLOW DIVIDE - SCENARIO 6



0002231

LEGEND:

EXTRACTION WELL

INJECTION WELL

SCALE

500 250 0 500 FEET

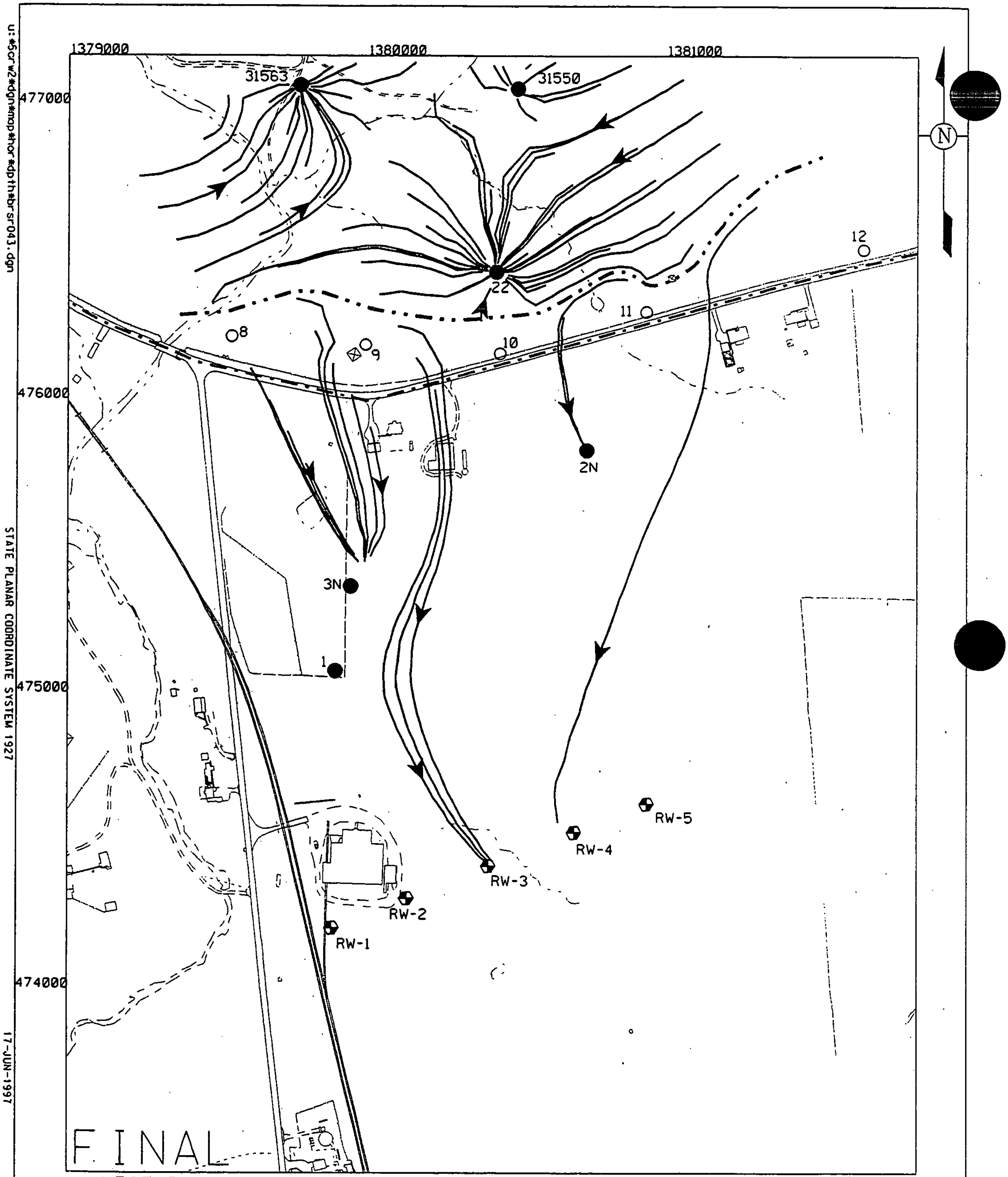
FINAL

FIGURE E-22. SIMULATED 10-YEAR CROSS-SECTIONAL
PARTICLE TRACKS - SCENARIO 7

u:*5crw2*dgn*map*hor*dpth*work019.dgn
STATE PLANAR COORDINATE SYSTEM 1927

17-JUN-1997

8651



LEGEND:

FEMP BOUNDARY

INDICATES DIRECTION OF FLOW

FLOW DIVIDE

000232

SCALE

450 225 0 450 FEET

FIGURE E-23. SIMULATED 10-YEAR AREAL PARTICLE TRACKS AND FLOW DIVIDE - SCENARIO 7

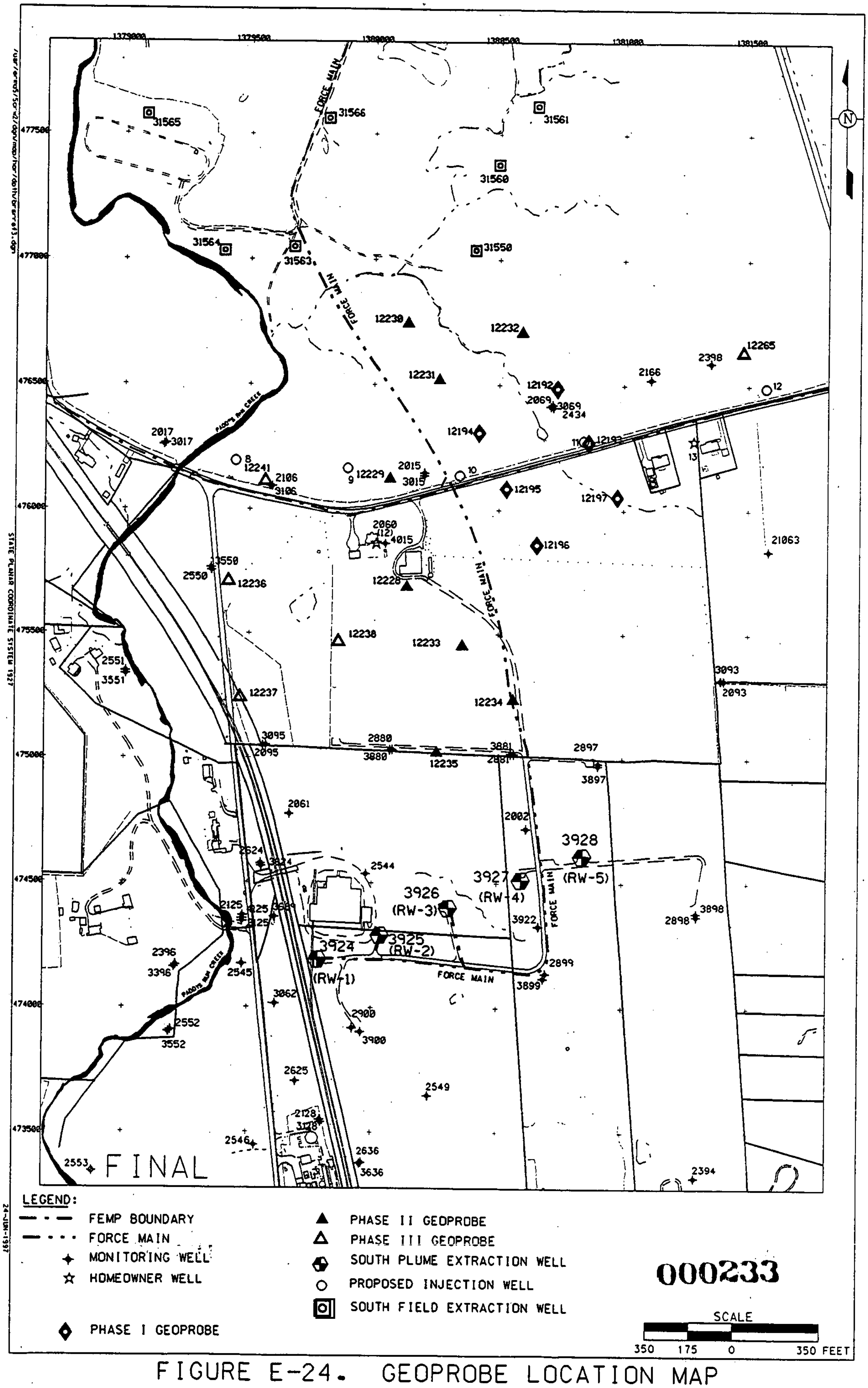
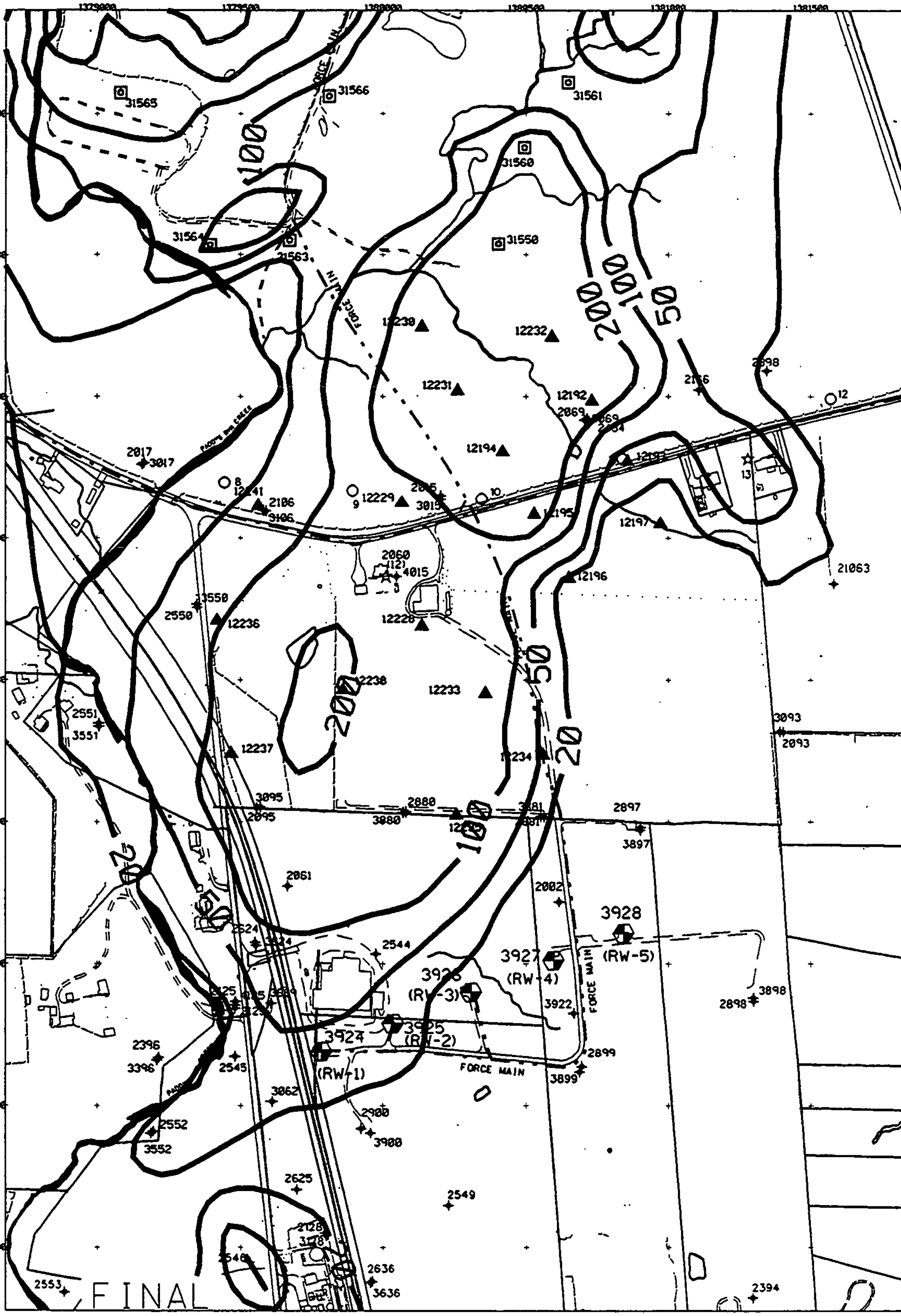


FIGURE E-24. GEOPROBE LOCATION MAP



LEGEND:

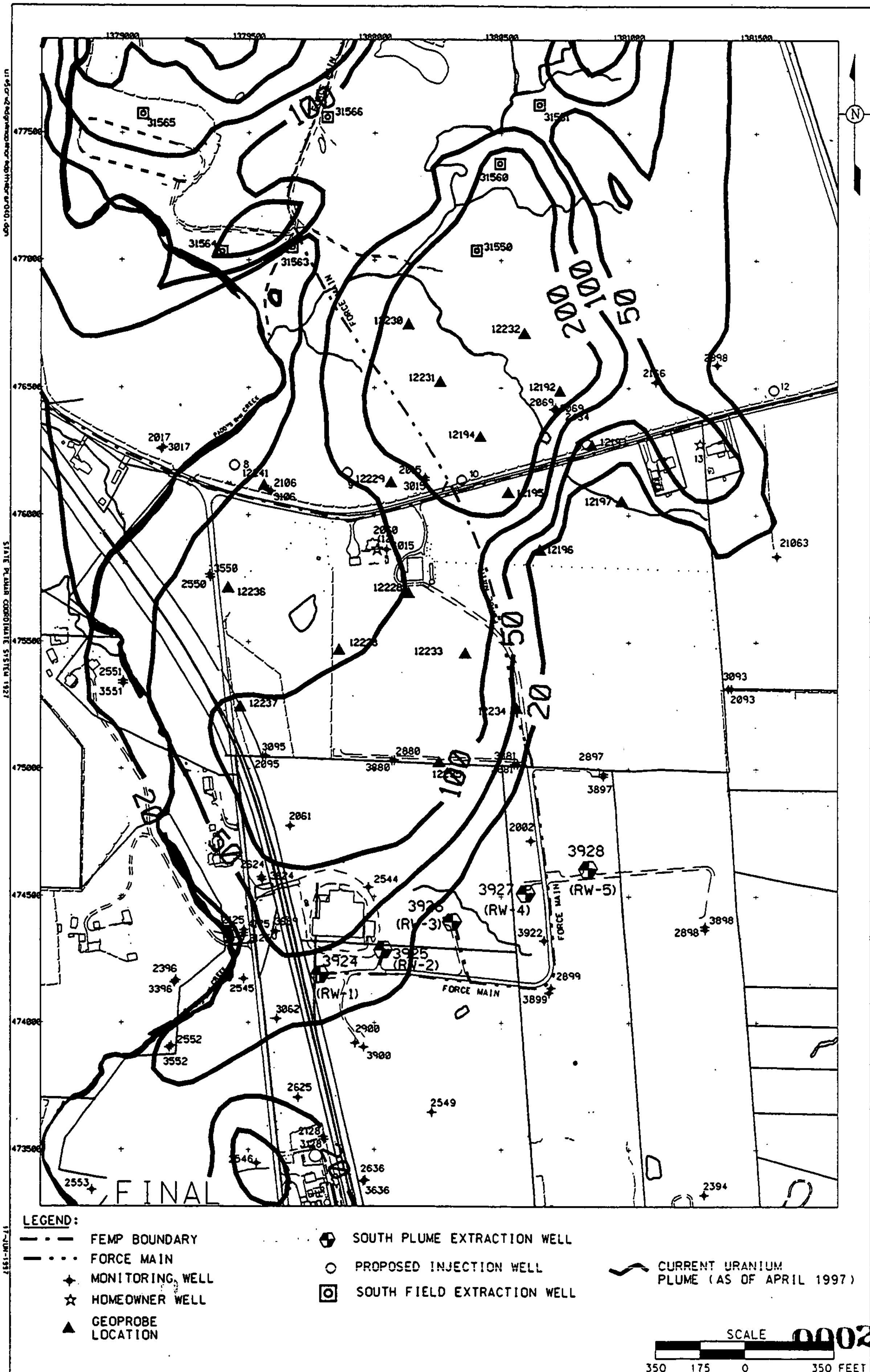
- FEMP BOUNDARY
- FORCE MAIN
- MONITORING WELL
- HOMEOWNER WELL
- GEOPROBE LOCATION
- GEOPROBE LOCATION (PROPOSED)
- SOUTH PLUME EXTRACTION WELL
- PROPOSED INJECTION WELL
- SOUTH FIELD EXTRACTION WELL
- URANIUM CONCENTRATION CONTOUR (ppb) (AS OF MARCH 1997)

SCALE

350 175 0 350 FEET

000234

FIGURE E-25. UPDATED URANIUM PLUME FOR MODELING SCENARIOS A-1 THROUGH A-12 AND B-1 THROUGH B-5 - WITH PARTIAL GEOPROBE RESULTS



000235

FIGURE E-26. UPDATED URANIUM PLUME FOR MODELING SCENARIOS C-1 AND C-2 - FINAL

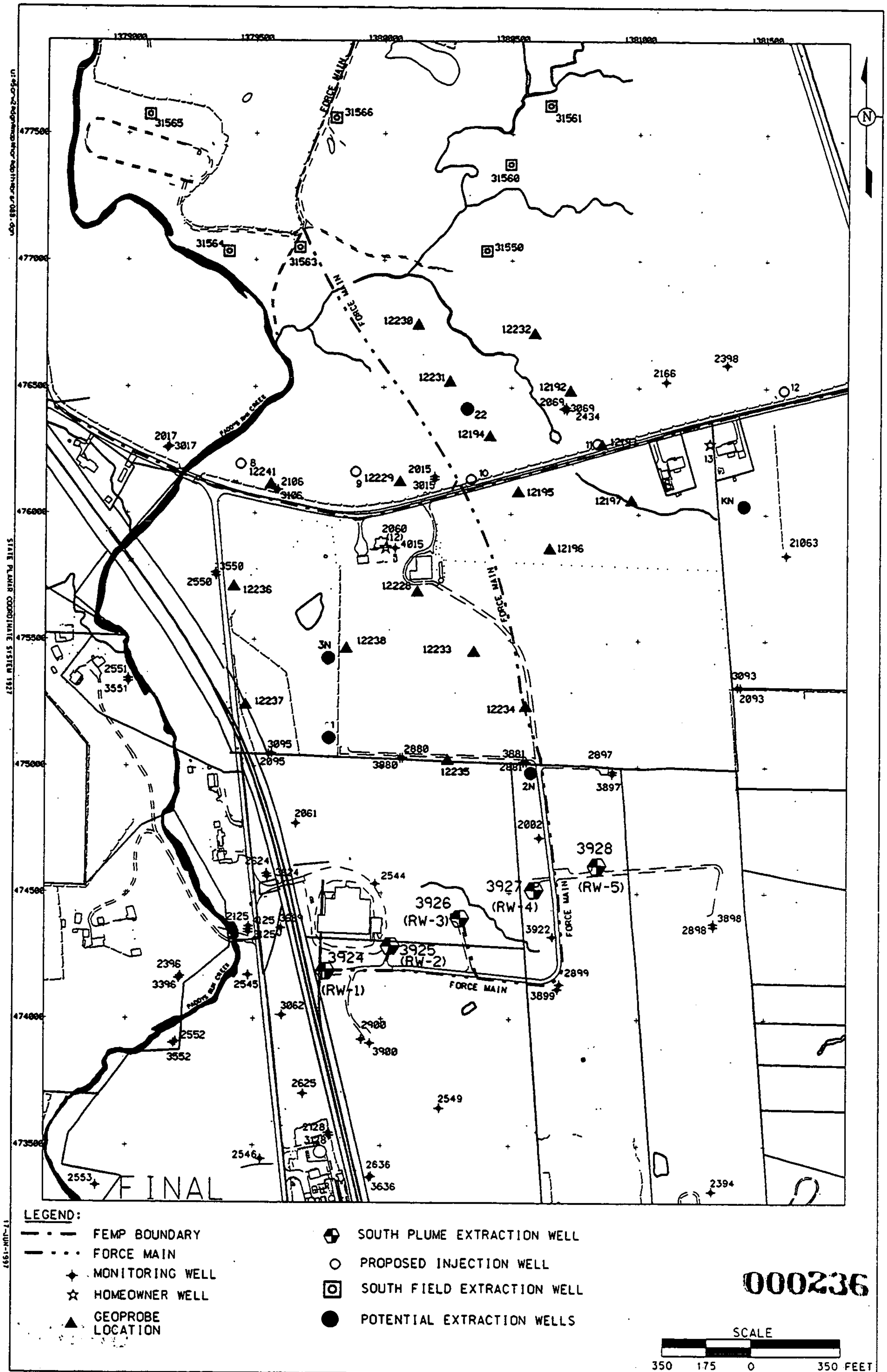
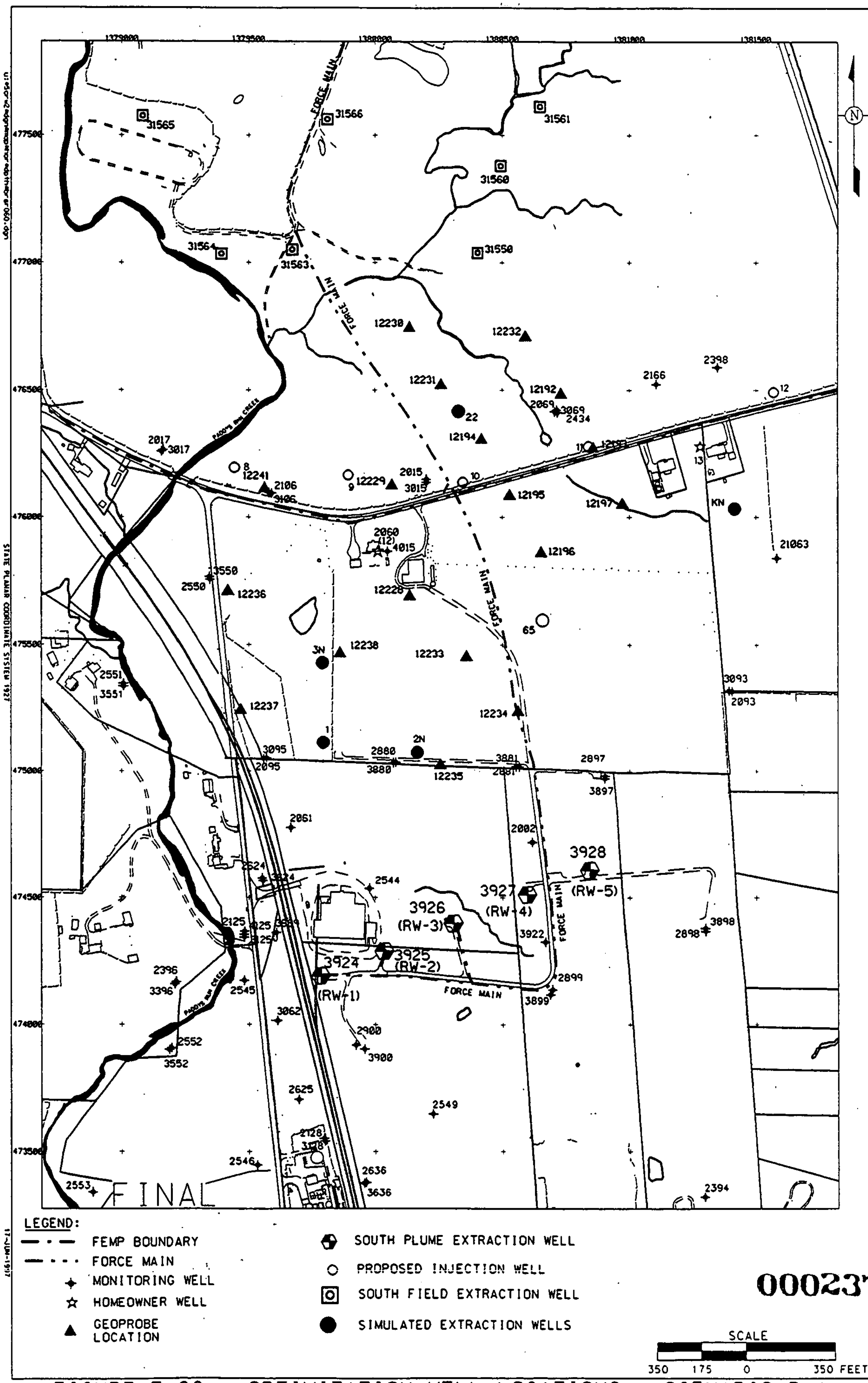


FIGURE E-27. PRELIMINARY OPTIMIZATION WELL LOCATIONS FOR STARTUP SCHEDULE EVALUATION

851



000237

FIGURE E-28. OPTIMIZATION WELL LOCATIONS - SCENARIO B-1

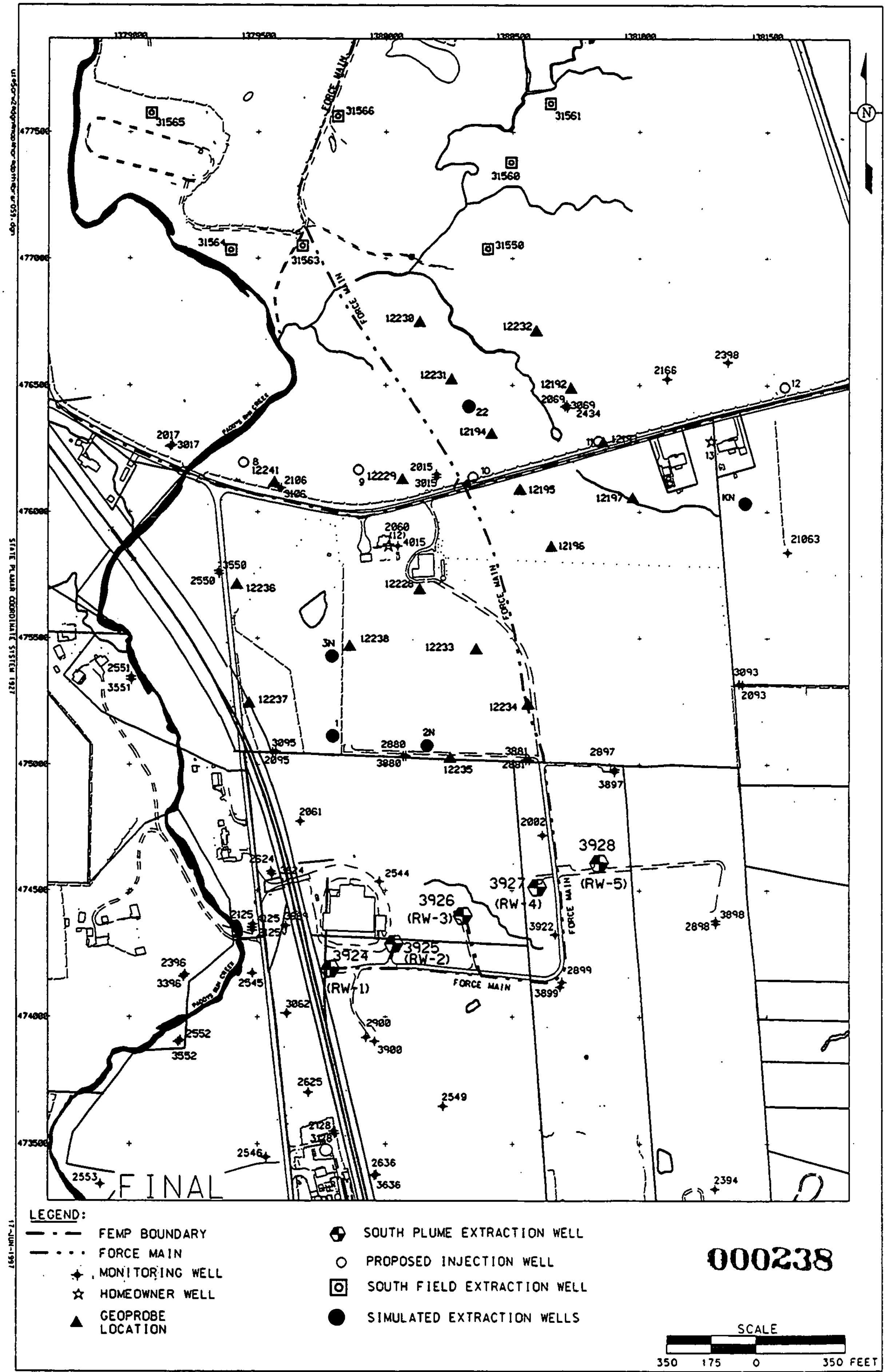
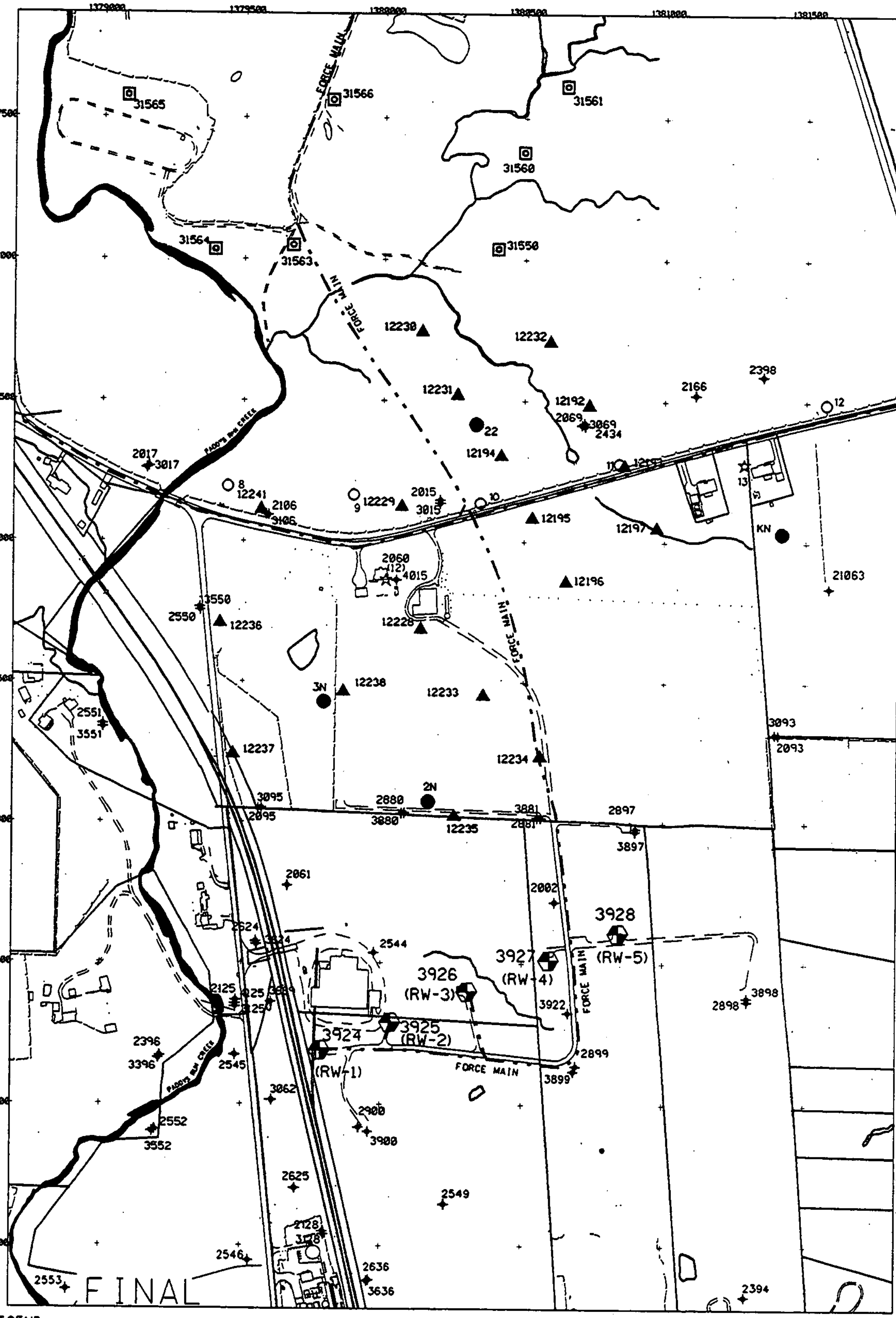


FIGURE E-29. OPTIMIZATION WELL LOCATIONS - SCENARIO B-2



LEGEND:

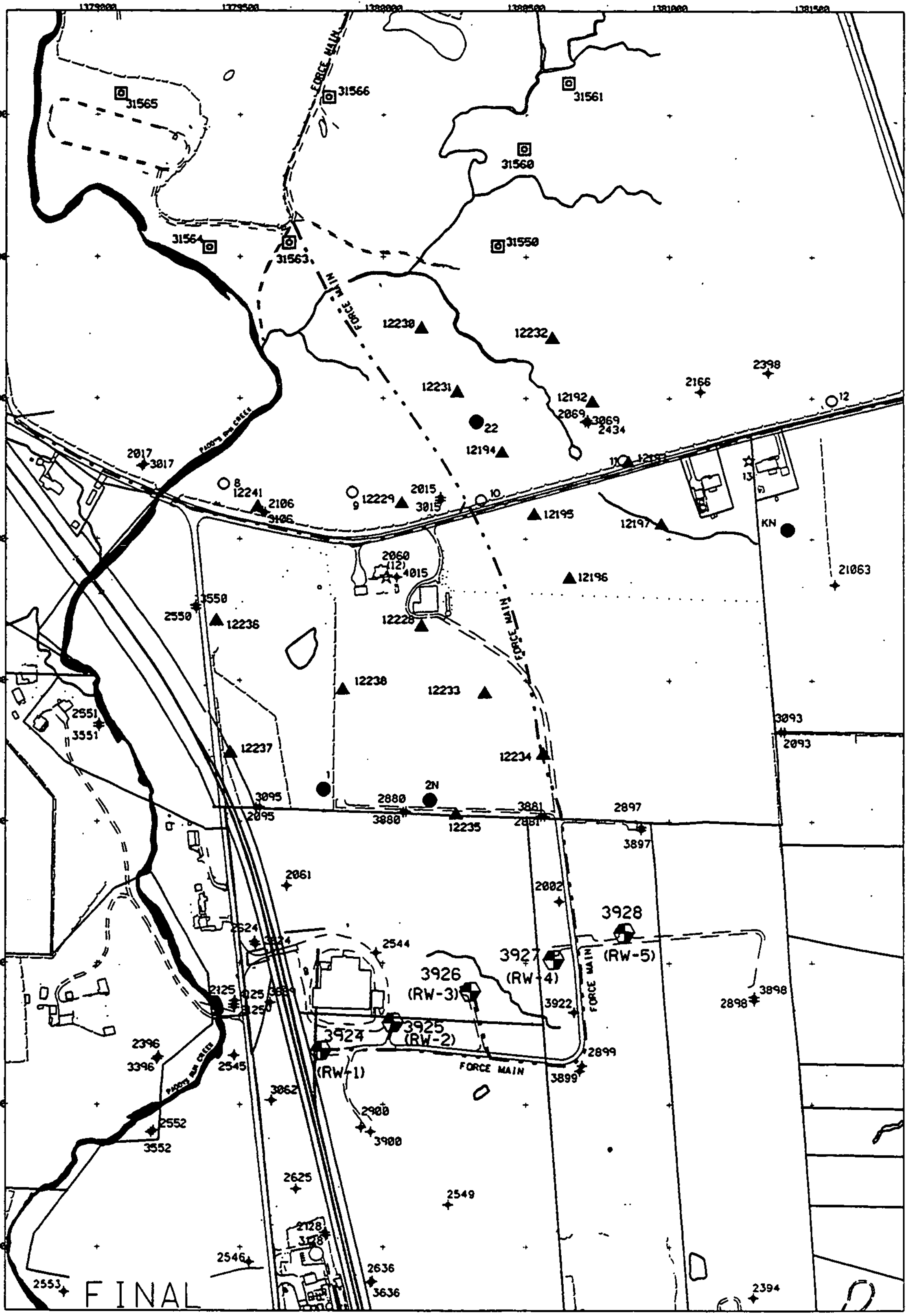
- FEMP BOUNDARY
- FORCE MAIN
- MONITORING WELL
- HOMEOWNER WELL
- GEOPROBE LOCATION
- SOUTH PLUME EXTRACTION WELL
- PROPOSED INJECTION WELL
- SOUTH FIELD EXTRACTION WELL
- SIMULATED EXTRACTION WELLS

000239

SCALE

350 175 0 350 FEET

FIGURE E-30. OPTIMIZATION WELL LOCATIONS - SCENARIOS B-3 AND B-4



LEGEND:

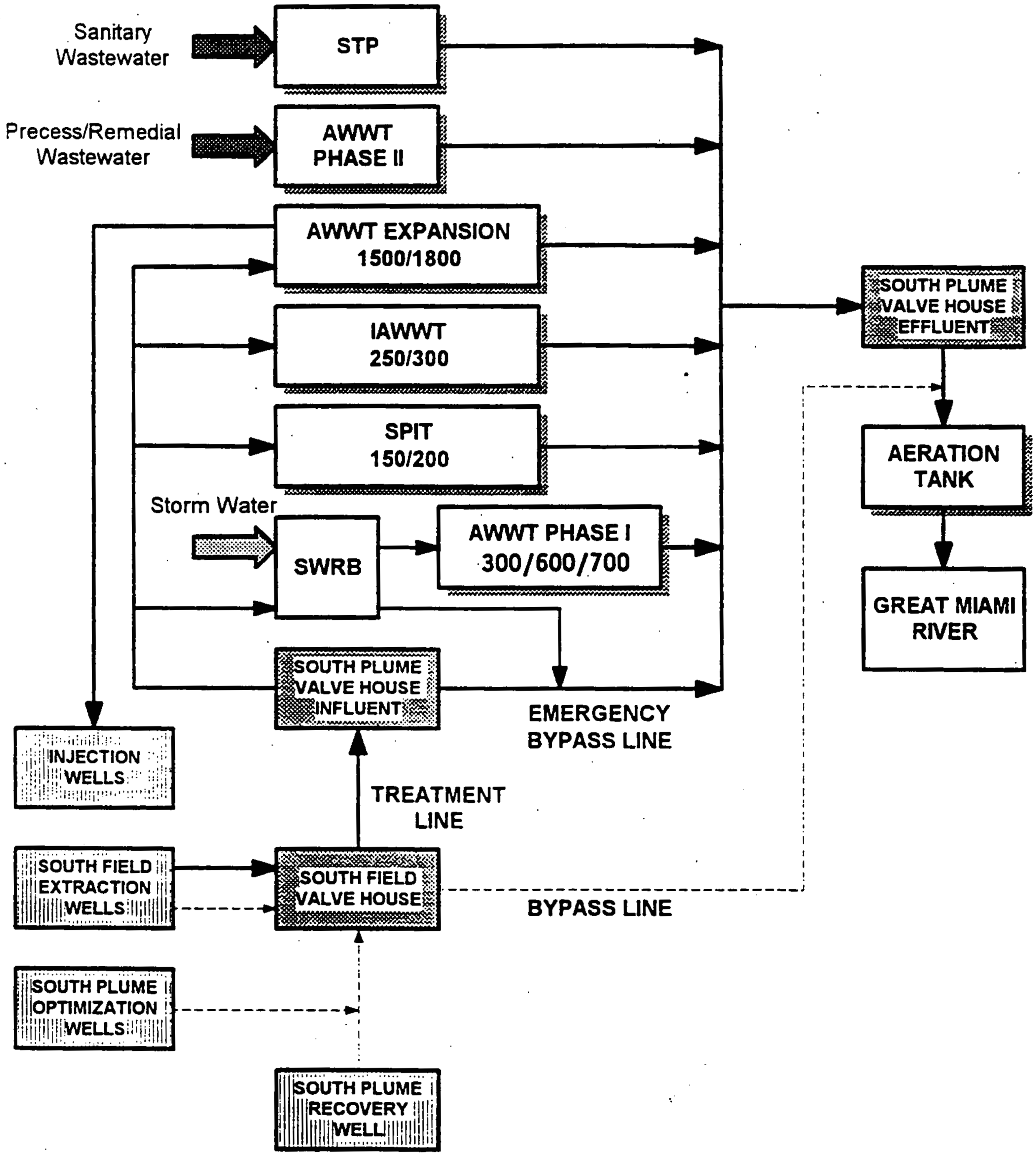
- FEMP BOUNDARY
- FORCE MAIN
- MONITORING WELL
- HOMEOWNER WELL
- GEOPROBE LOCATION
- SOUTH PLUME EXTRACTION WELL
- PROPOSED INJECTION WELL
- SOUTH FIELD EXTRACTION WELL
- SIMULATED EXTRACTION WELLS

SCALE

350 175 0 350 FEET

000240

FIGURE E-31. OPTIMIZATION WELL LOCATIONS - SCENARIO B-5

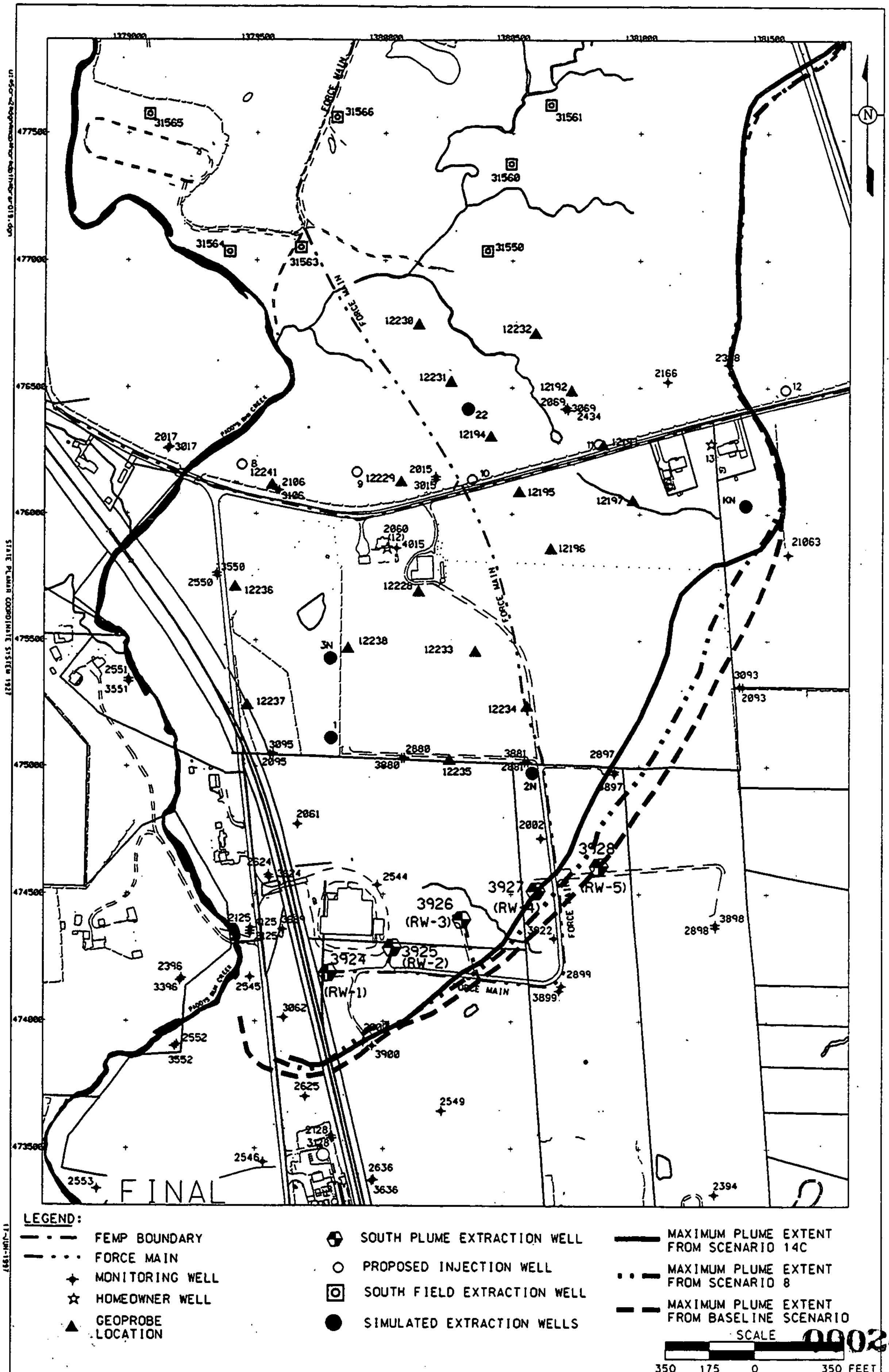


PLANNED GROUNDWATER TREATMENT CAPACITY
Reliable/Name-Plate Capacities

FINAL

000241

Figure E-32. Groundwater Treatment Capacity and Flow Routing Network



000242

FIGURE E-33. RANGE OF MAXIMUM PLUME EXTENTS FROM SCENARIOS A-1 THROUGH A-12

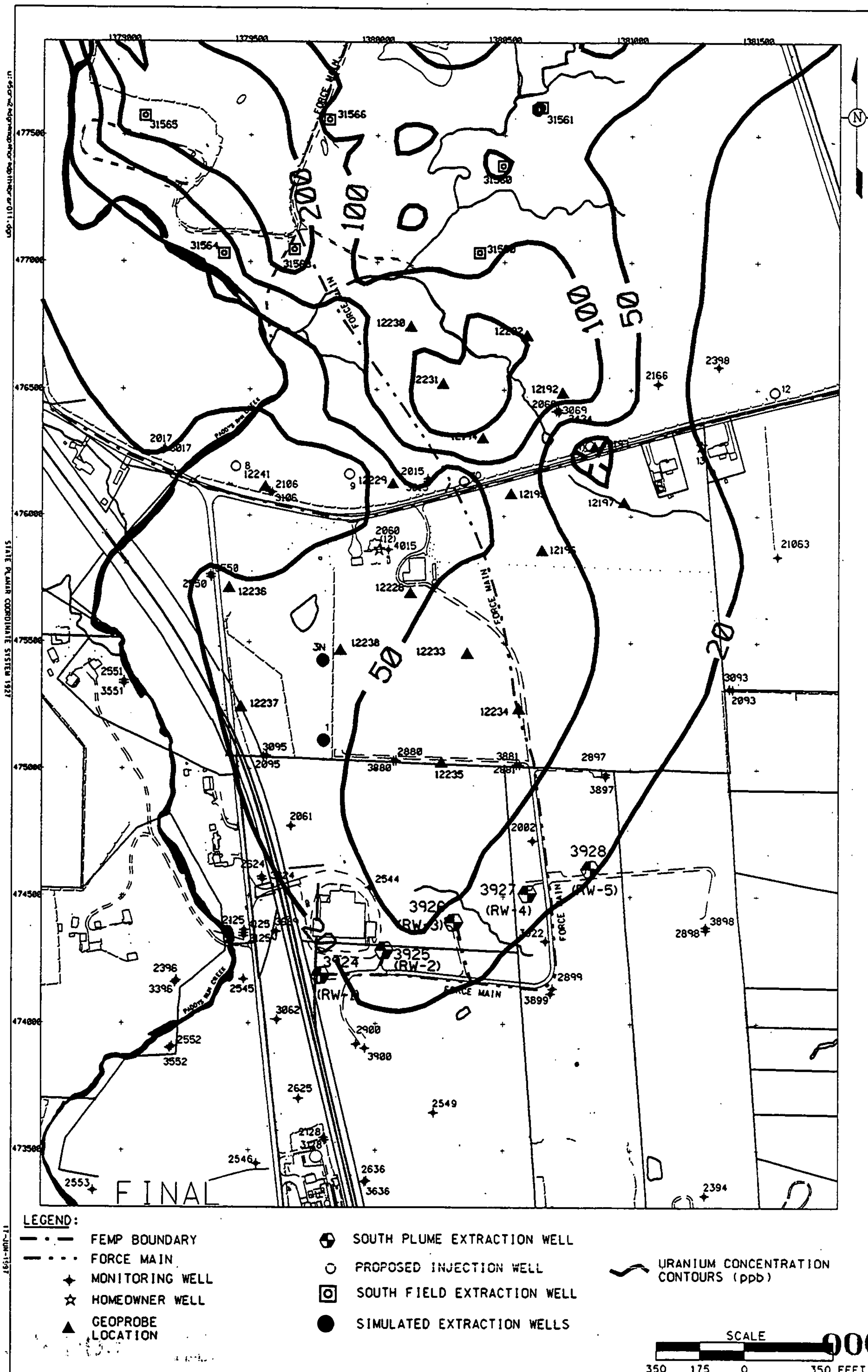
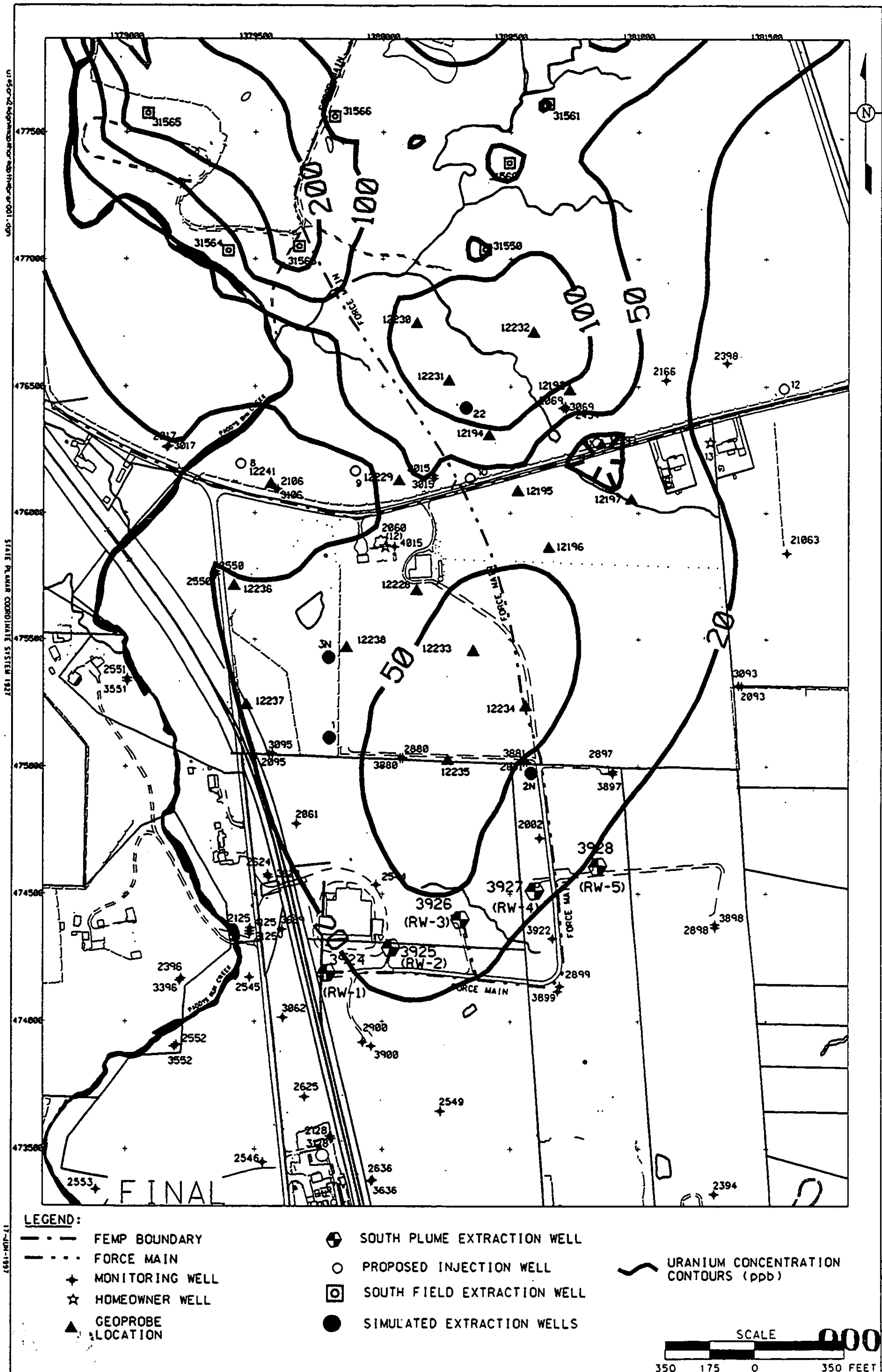


FIGURE E-34. RESIDUAL URANIUM PLUME AT THE END OF FY2003 - SCENARIO A-1



000244

FIGURE E-35. RESIDUAL URANIUM PLUME AT THE END OF FY2003 - SCENARIO A-2

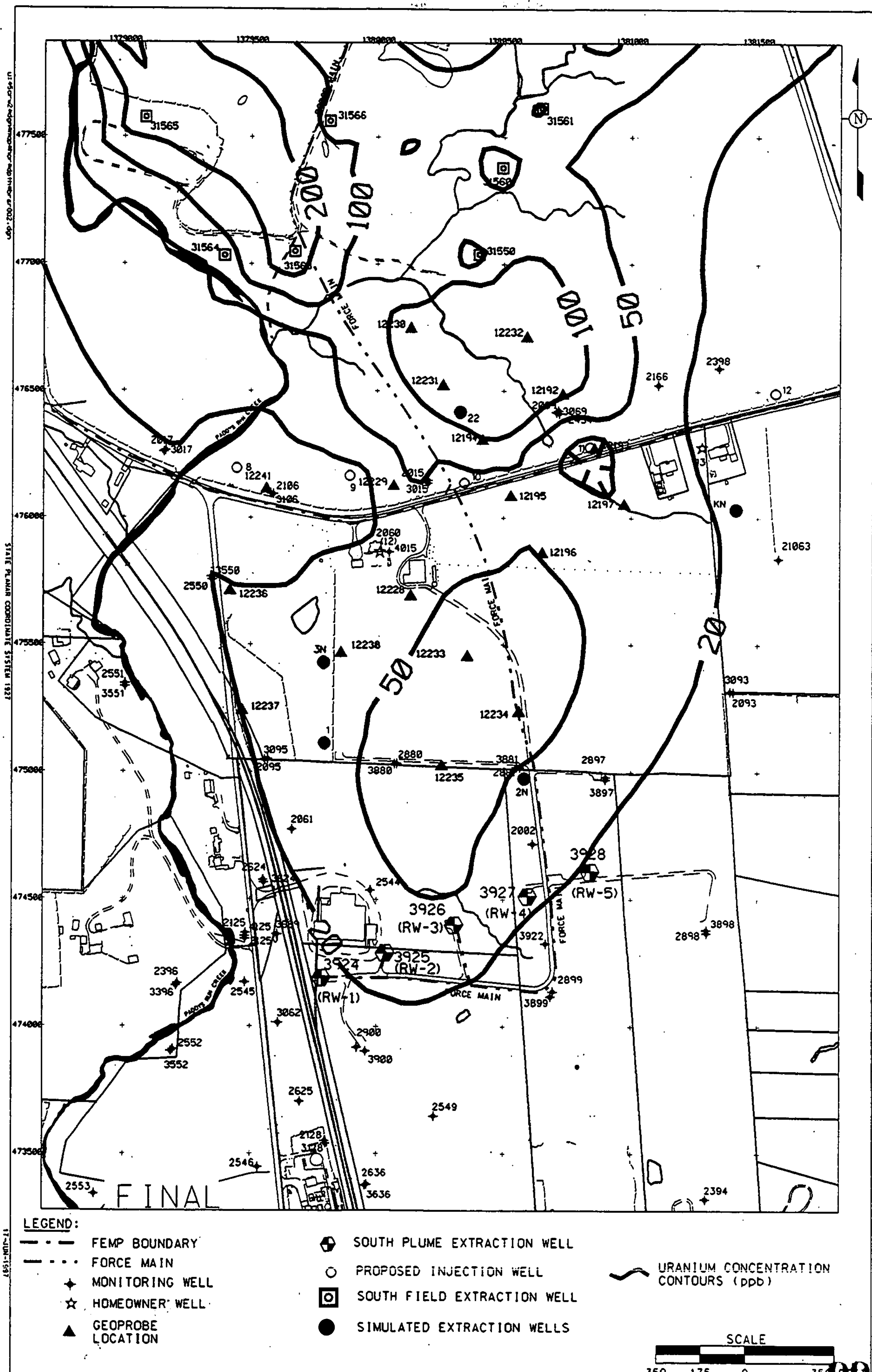
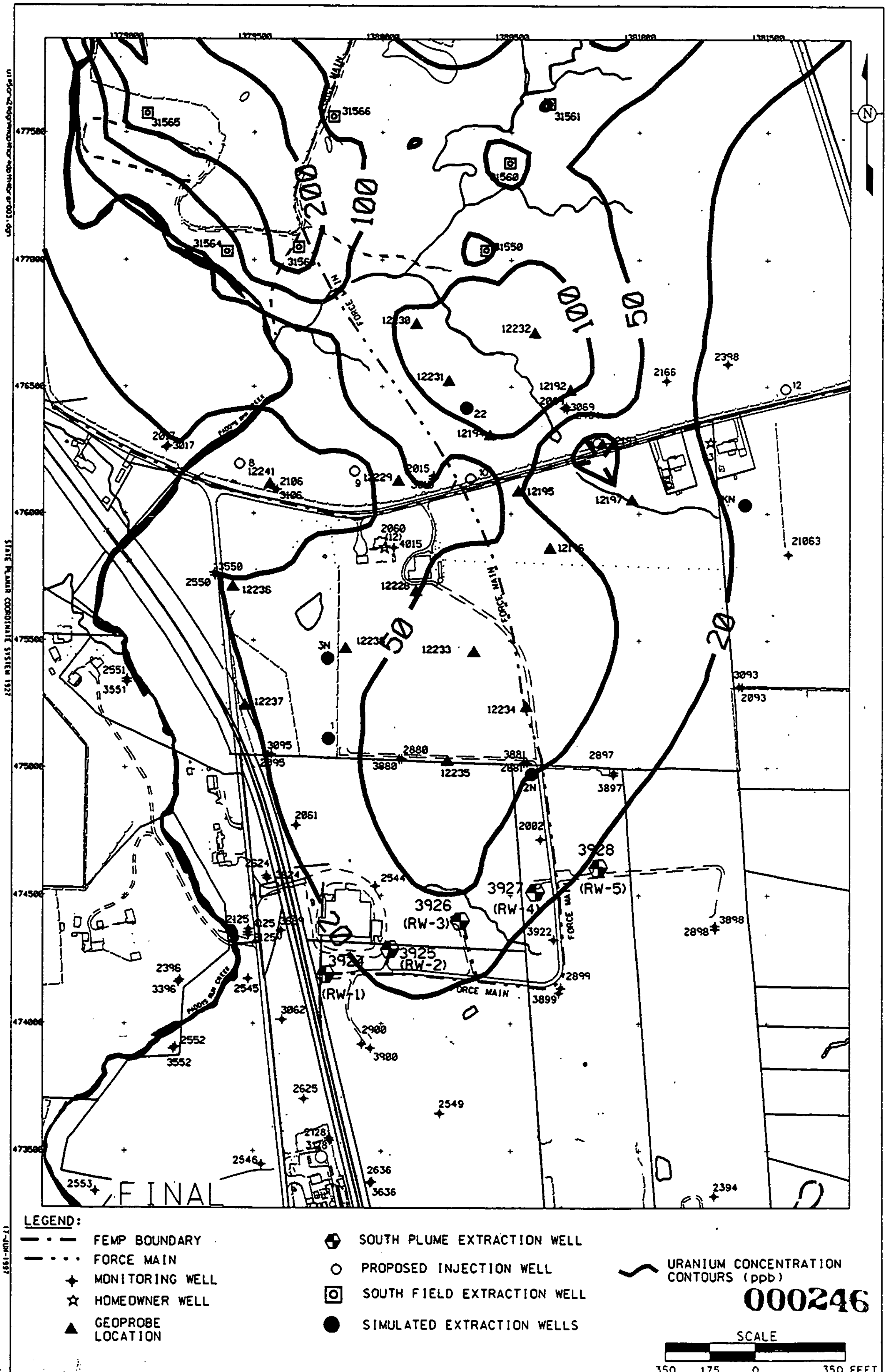


FIGURE E-36. RESIDUAL URANIUM PLUME AT THE END OF FY2003 - SCENARIO A-3



000246

FIGURE E-37. RESIDUAL URANIUM PLUME AT THE END OF FY2003 - SCENARIO A-4

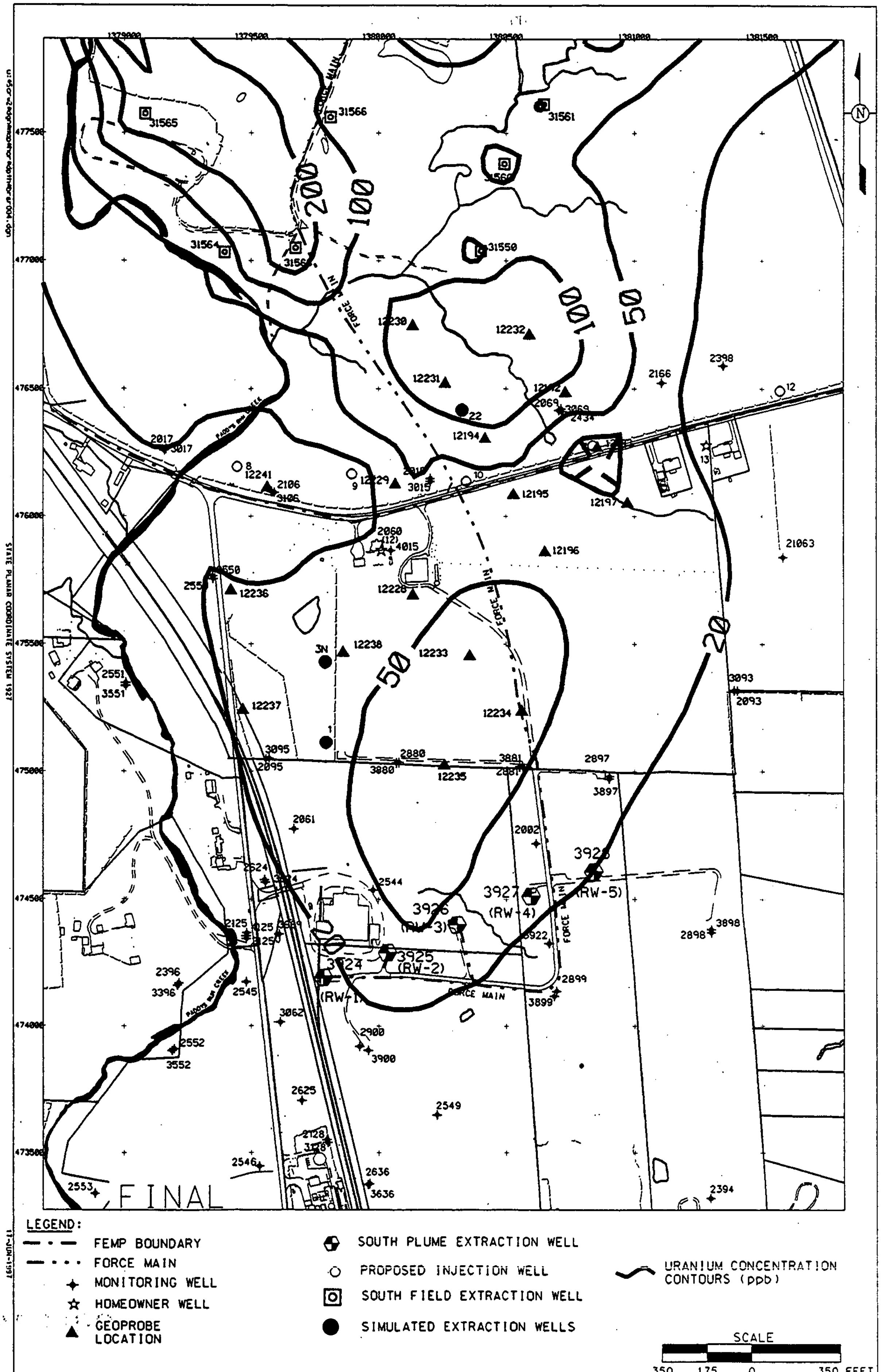


FIGURE E-38. RESIDUAL URANIUM PLUME AT THE END OF FY2003 - SCENARIO A-5

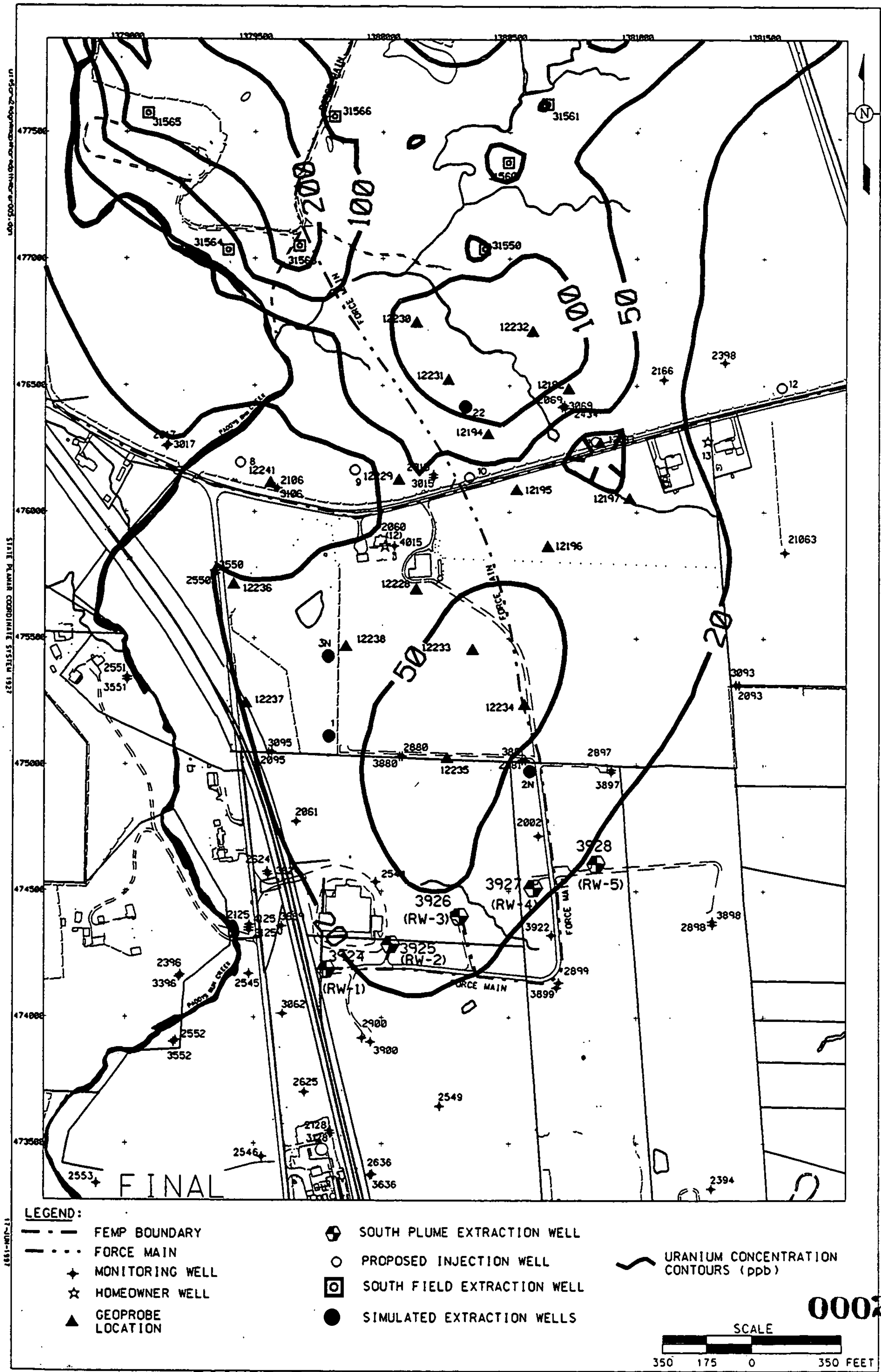


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FIGURE E-39. RESIDUAL URANIUM PLUME AT THE END OF FY2003 - SCENARIO A-6

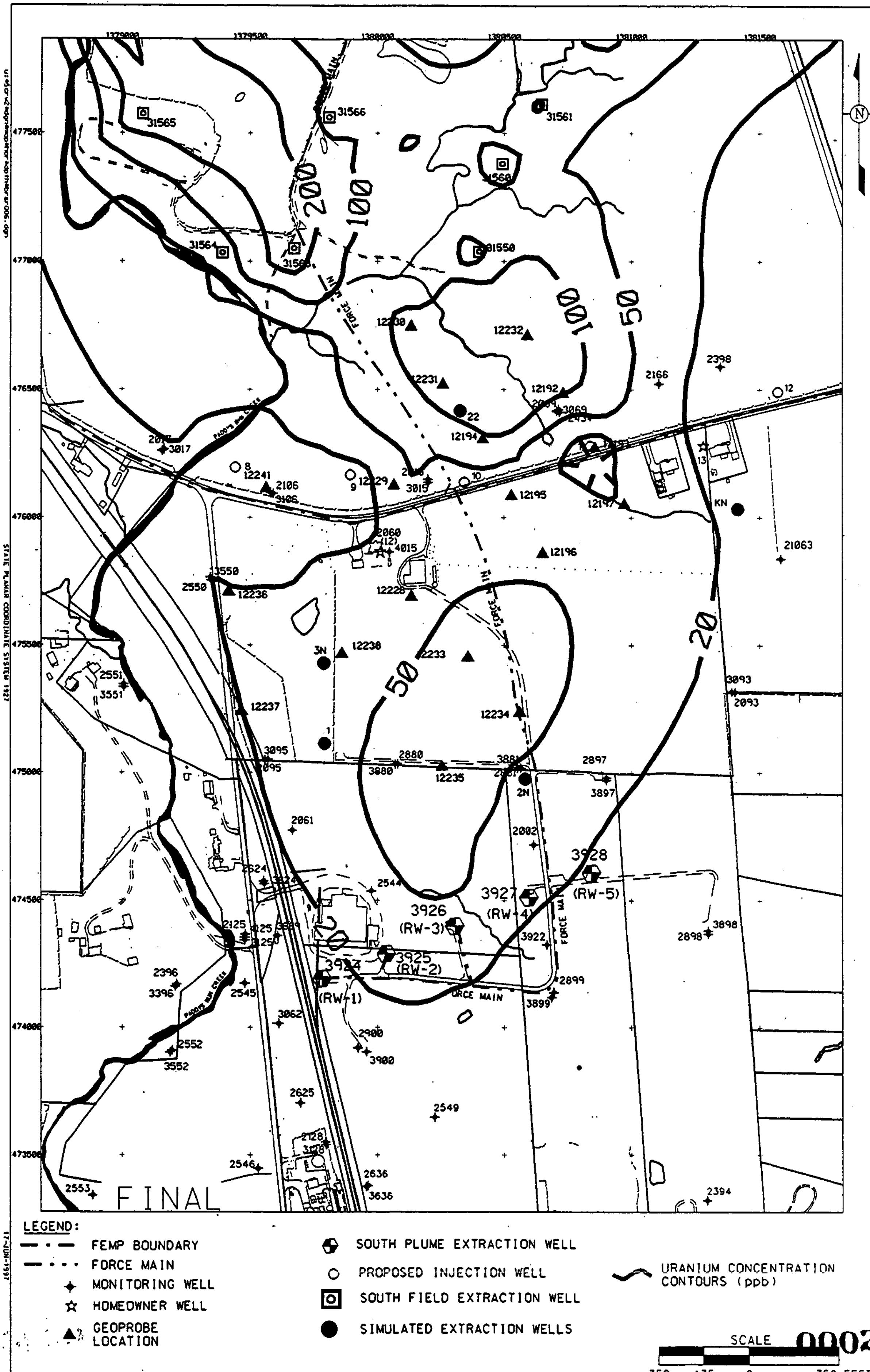

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FIGURE E-40. RESIDUAL URANIUM PLUME AT THE END OF FY2003 - SCENARIO A-7

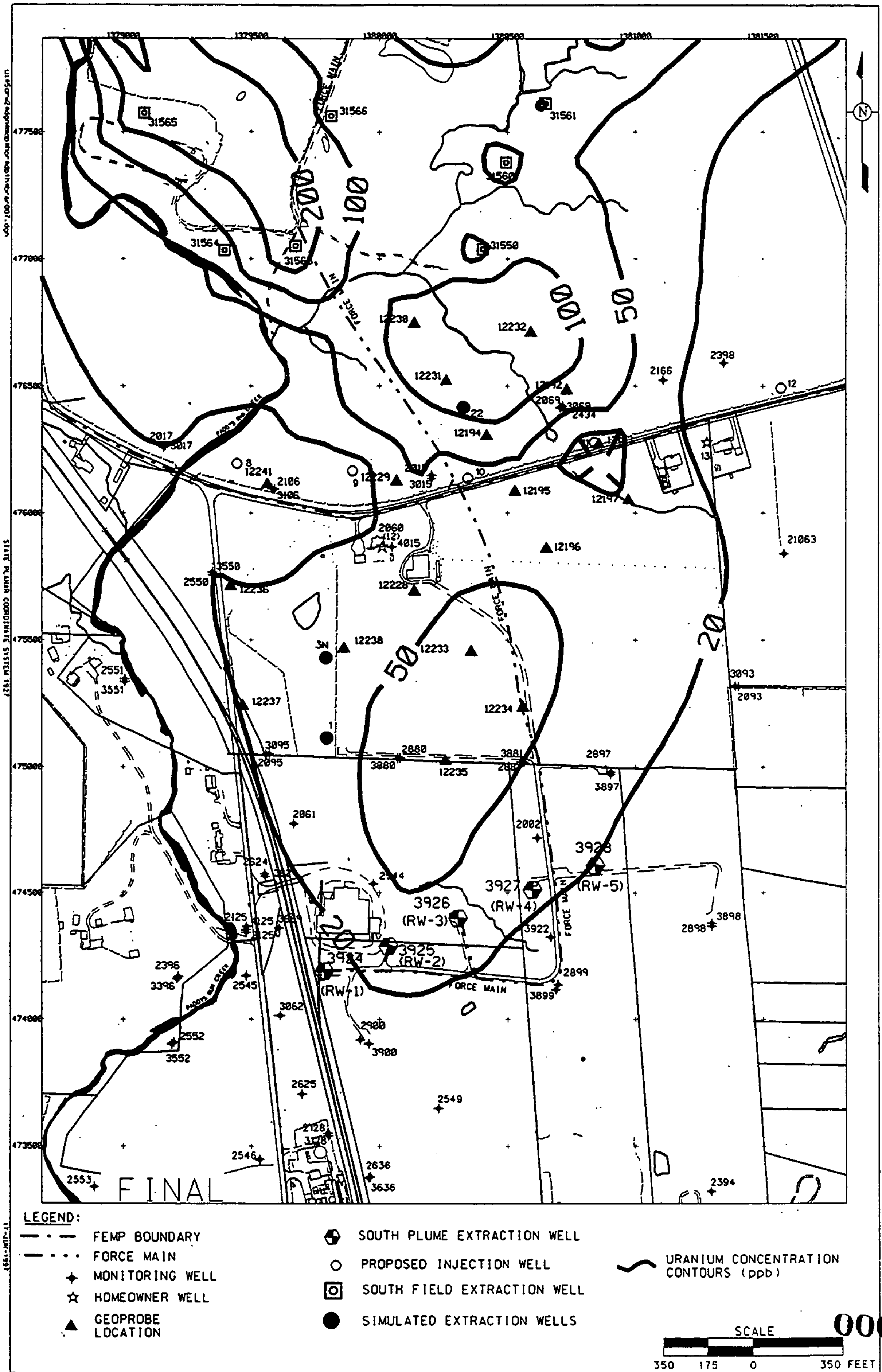

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FIGURE E-41. RESIDUAL URANIUM PLUME
AT THE END OF FY2003 - SCENARIO A-8

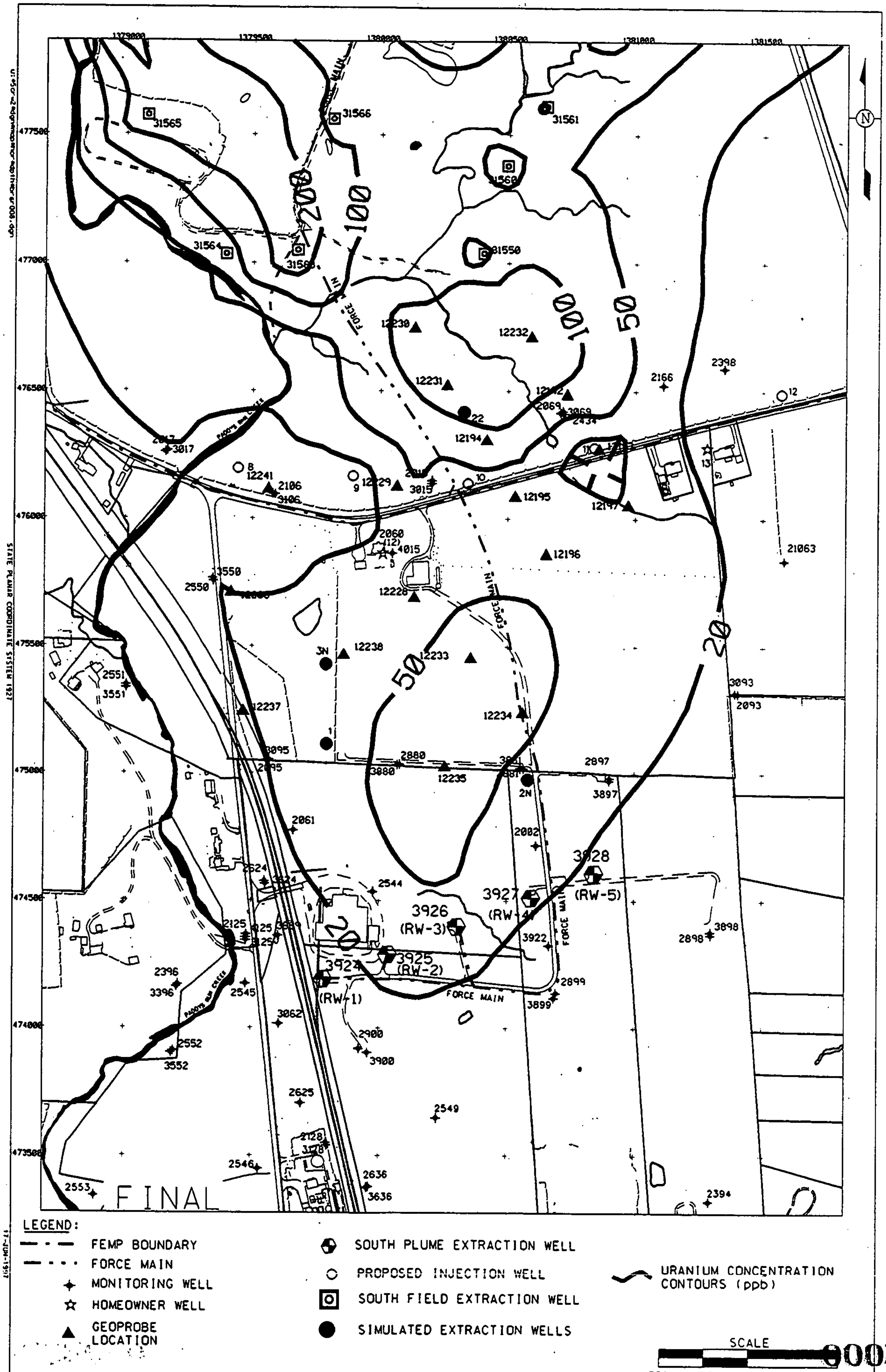

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FIGURE E-42. RESIDUAL URANIUM PLUME AT THE END OF FY2003 - SCENARIO A-9

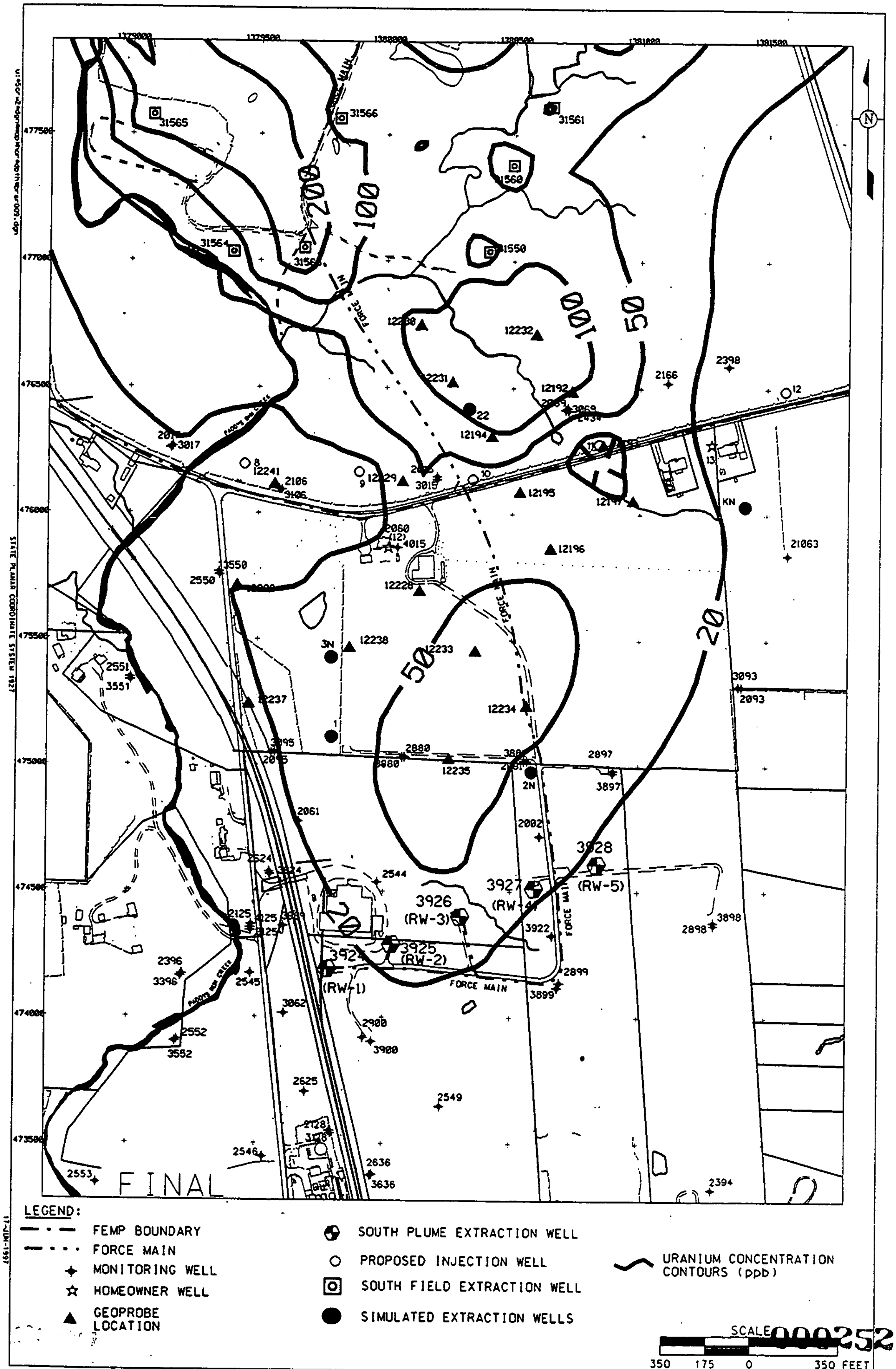

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FIGURE E-43. RESIDUAL URANIUM PLUME AT THE END OF FY2003 - SCENARIO A-10

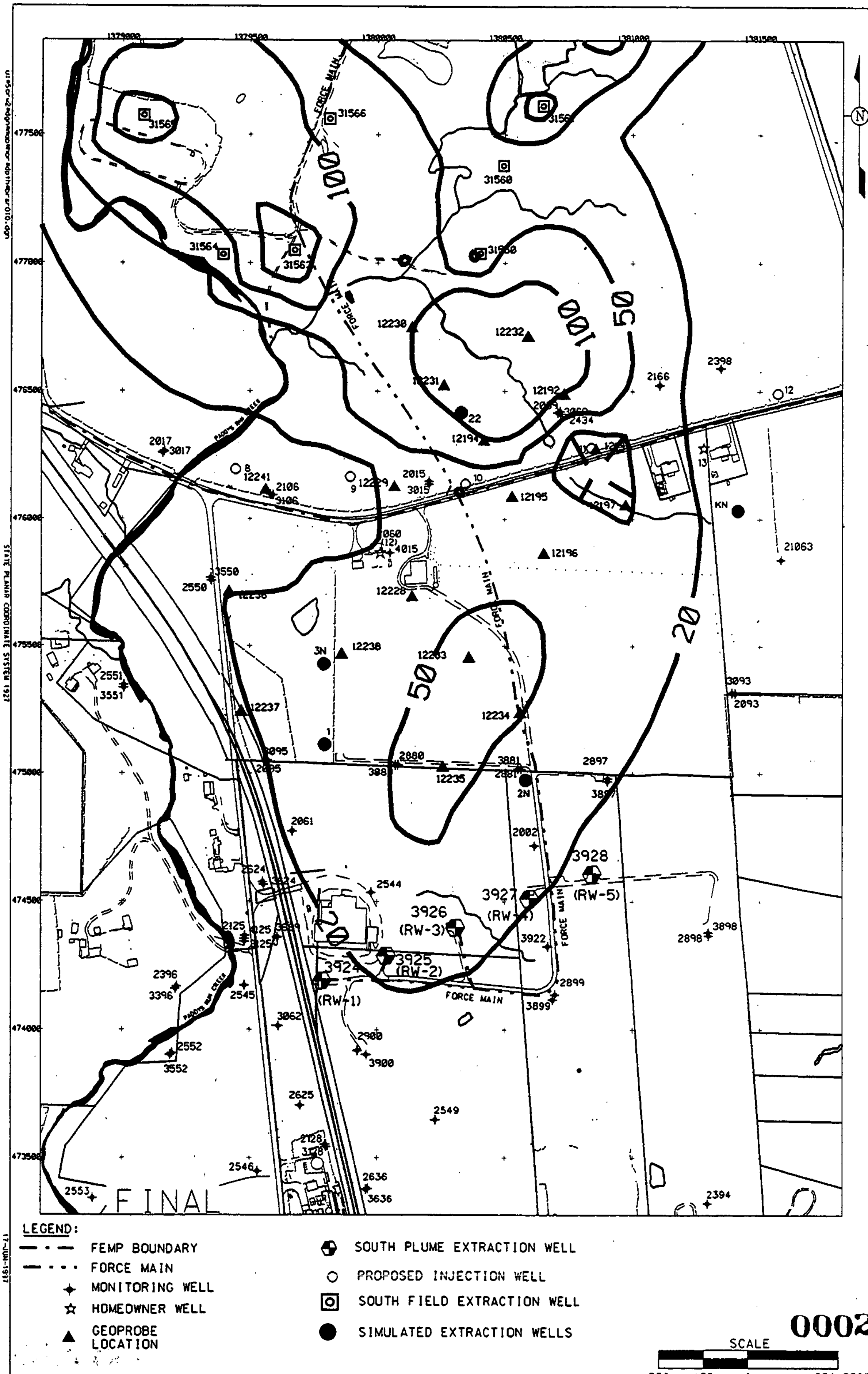

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FIGURE E-44. RESIDUAL URANIUM PLUME AT THE END OF FY2003 - SCENARIO A-11

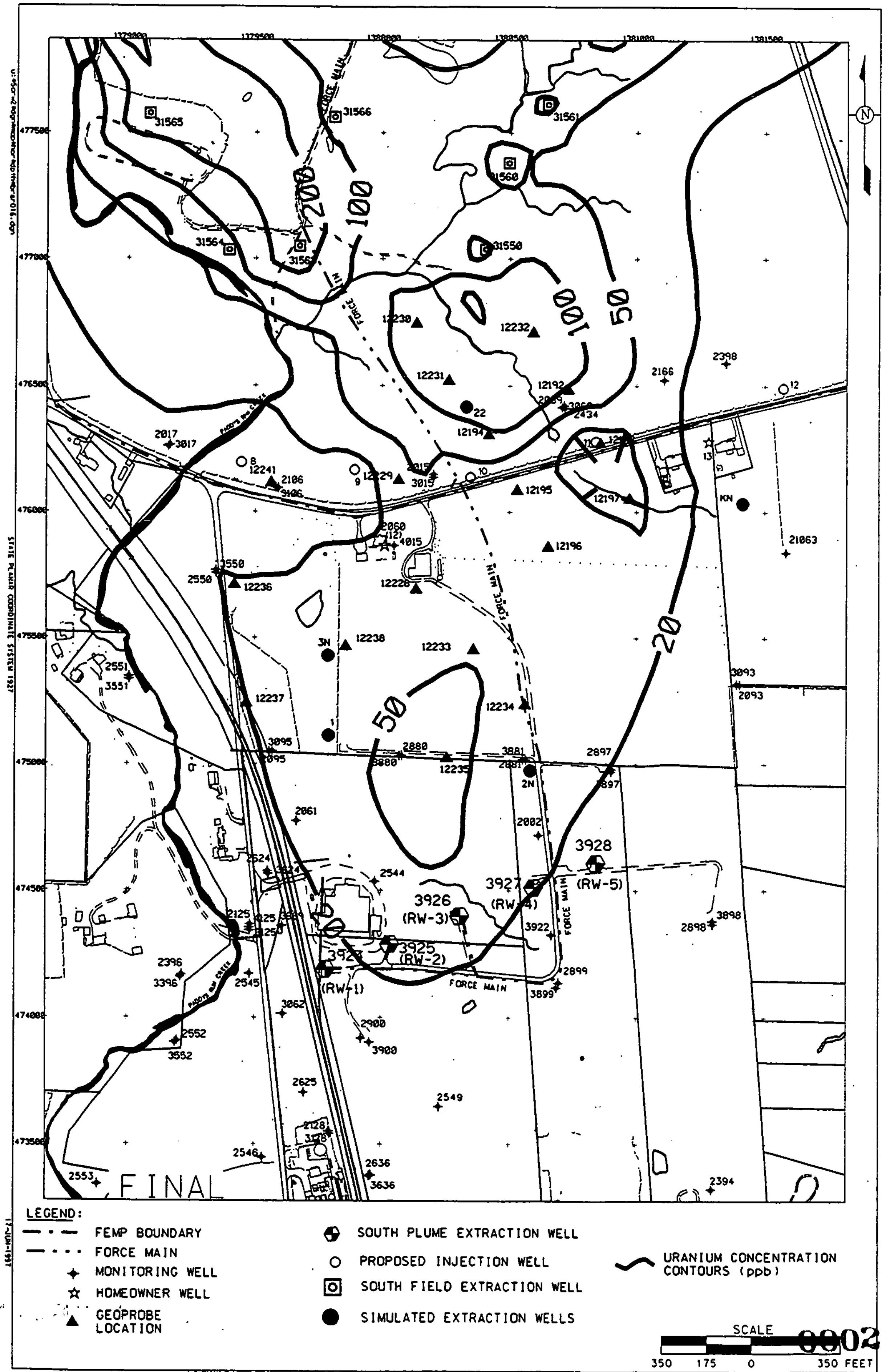

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FIGURE E-45. RESIDUAL URANIUM PLUME AT THE END OF FY2003 - SCENARIO A-12

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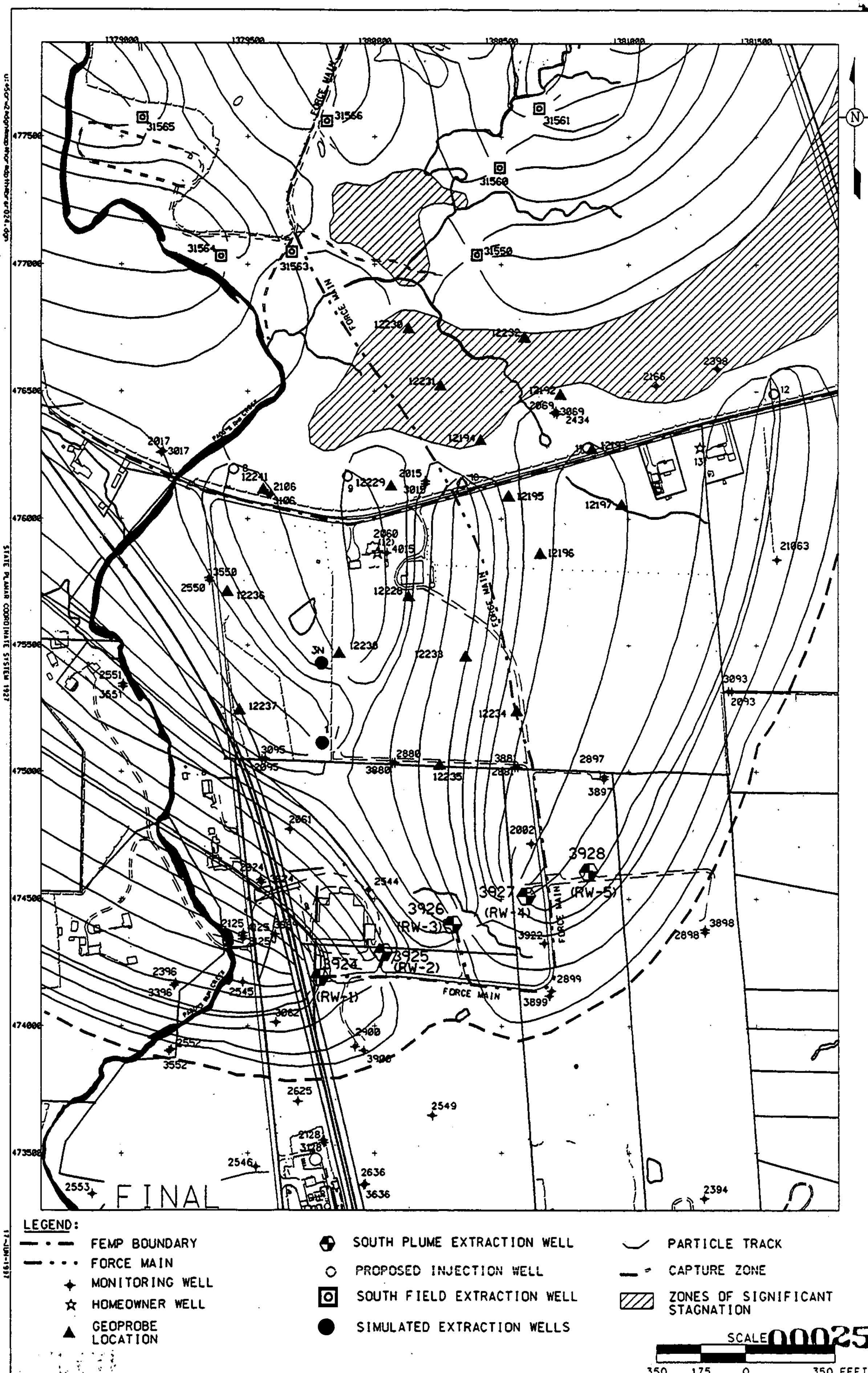

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FIGURE E-46. FIVE YEAR CAPTURE ZONE FOR SCENARIO A-1 (NO RETARDATION)

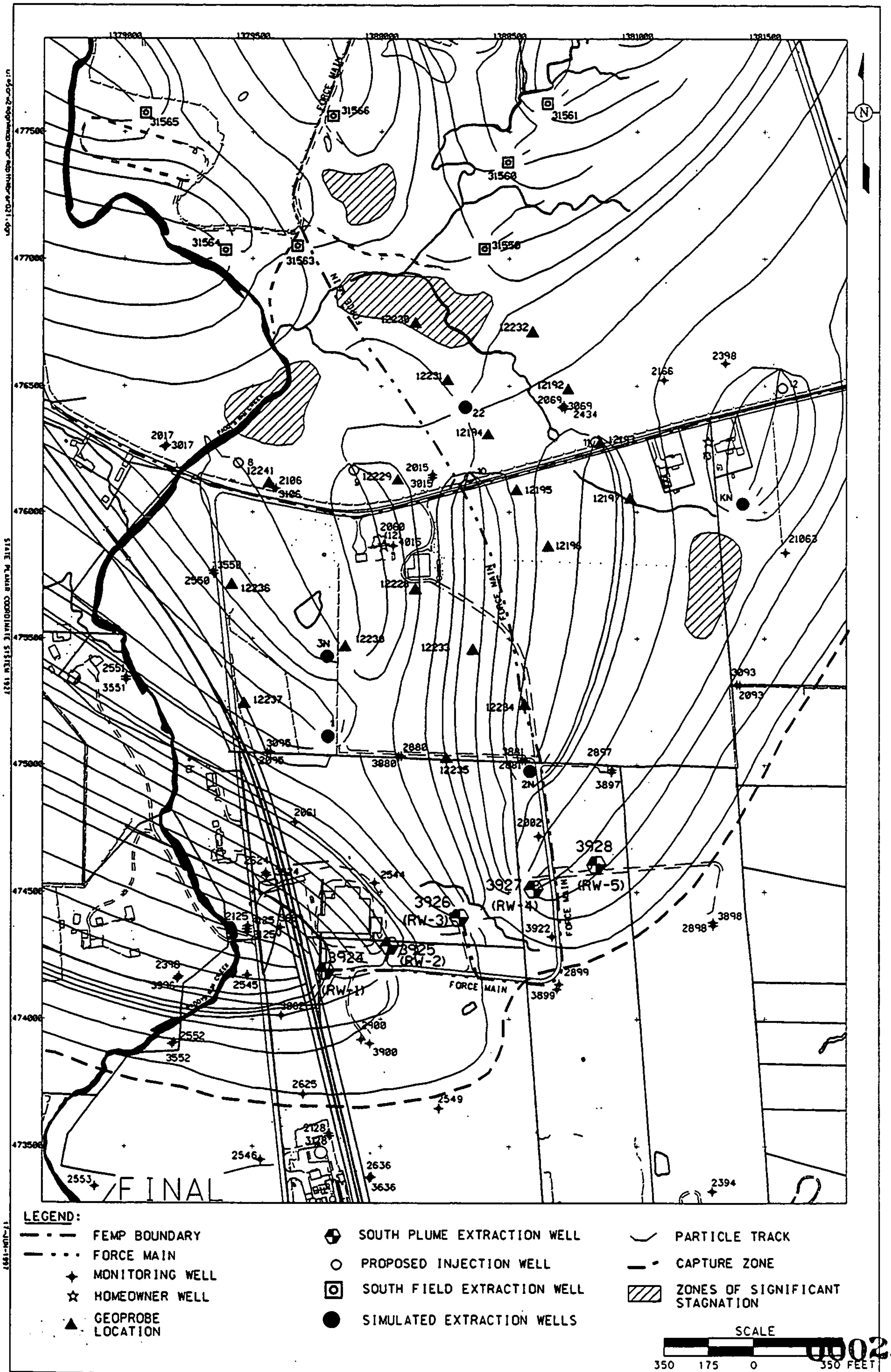

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FIGURE E-47. FIVE YEAR CAPTURE ZONE FOR SCENARIOS A-3, A-4, A-7, A-10, A-11 AND A-12 (NO RETARDATION)

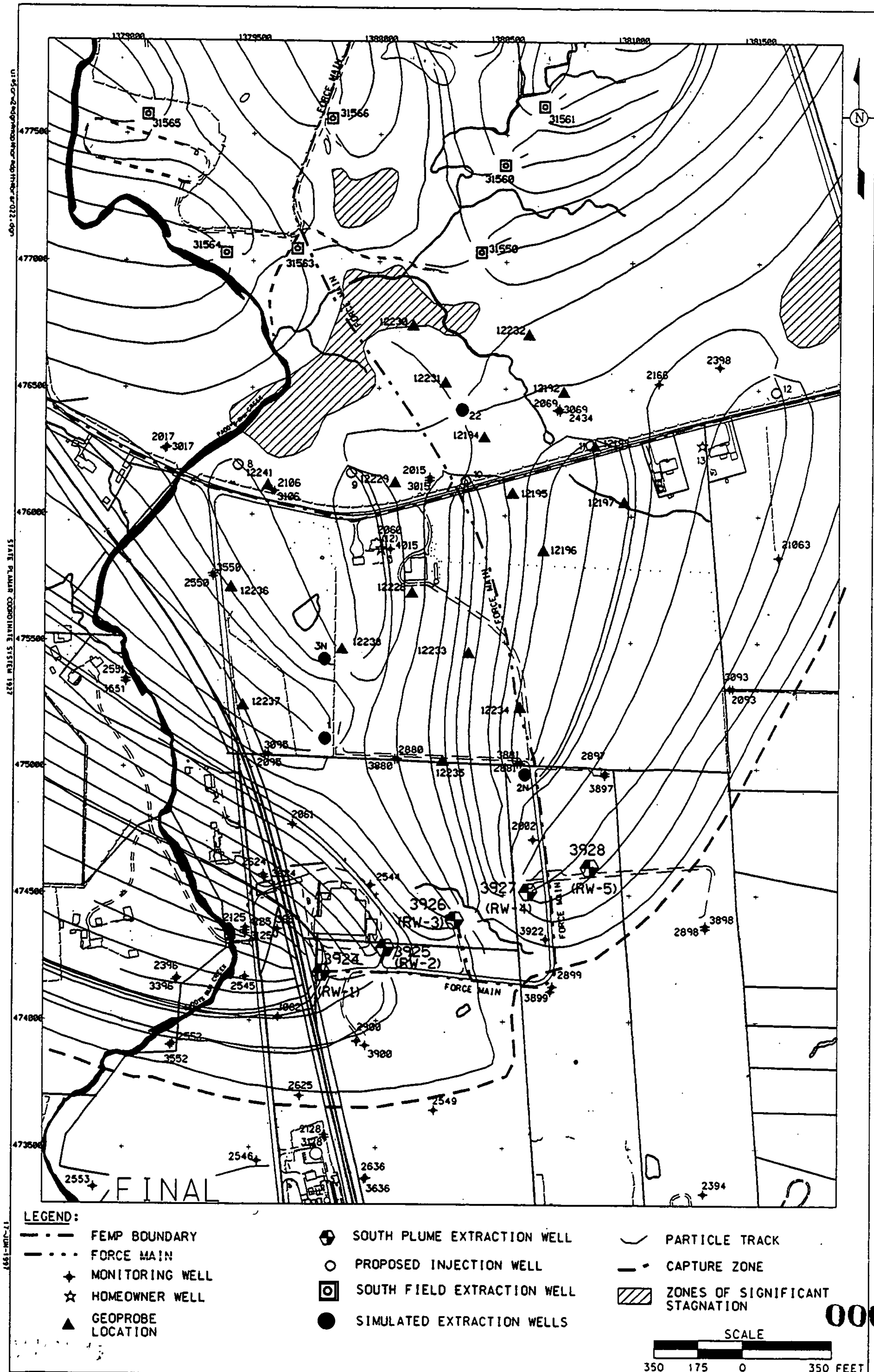

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FIGURE E-48. FIVE YEAR CAPTURE ZONE FOR SCENARIOS A-2, A-6 AND A-9 (NO RETARDATION)

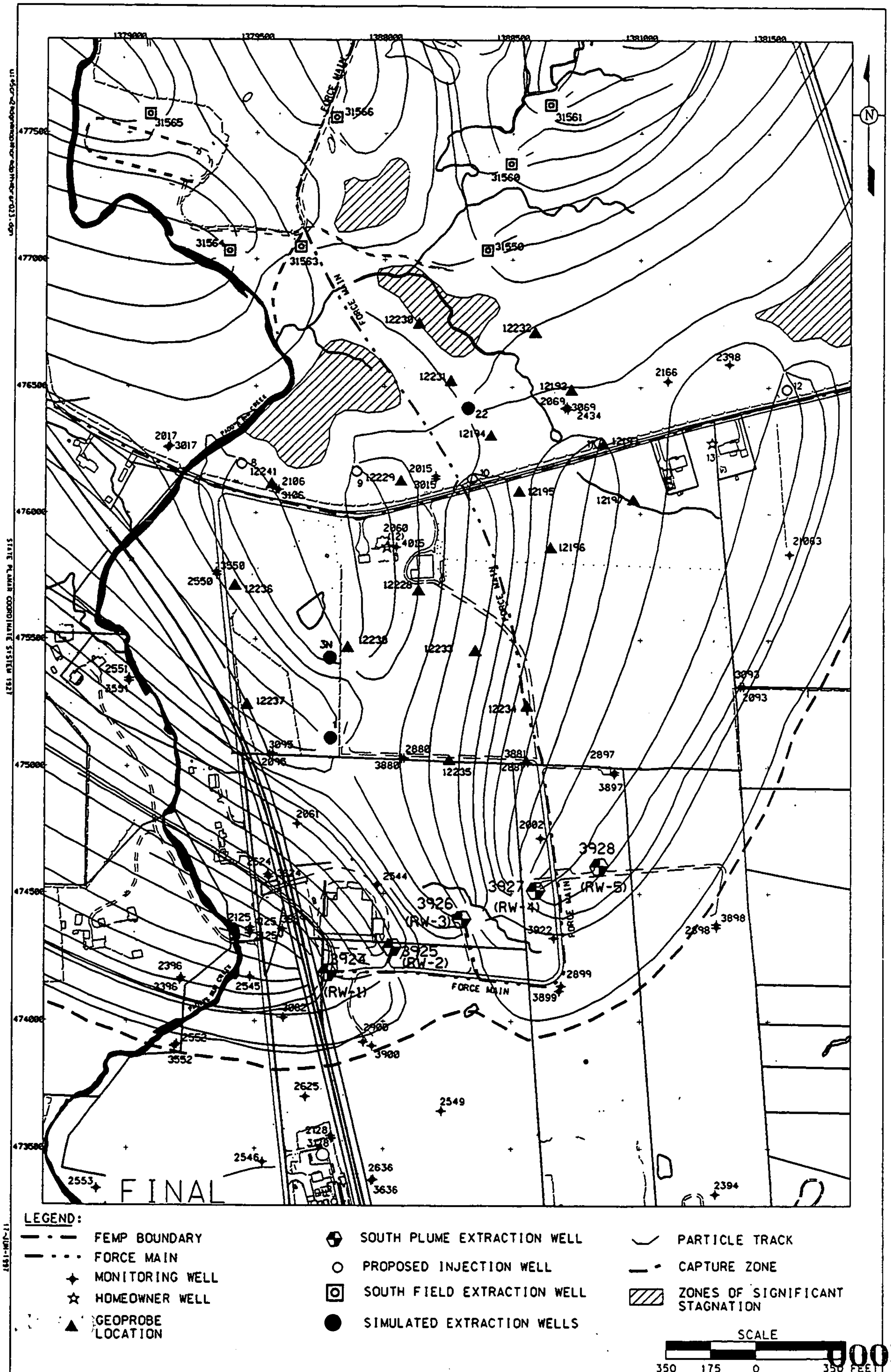

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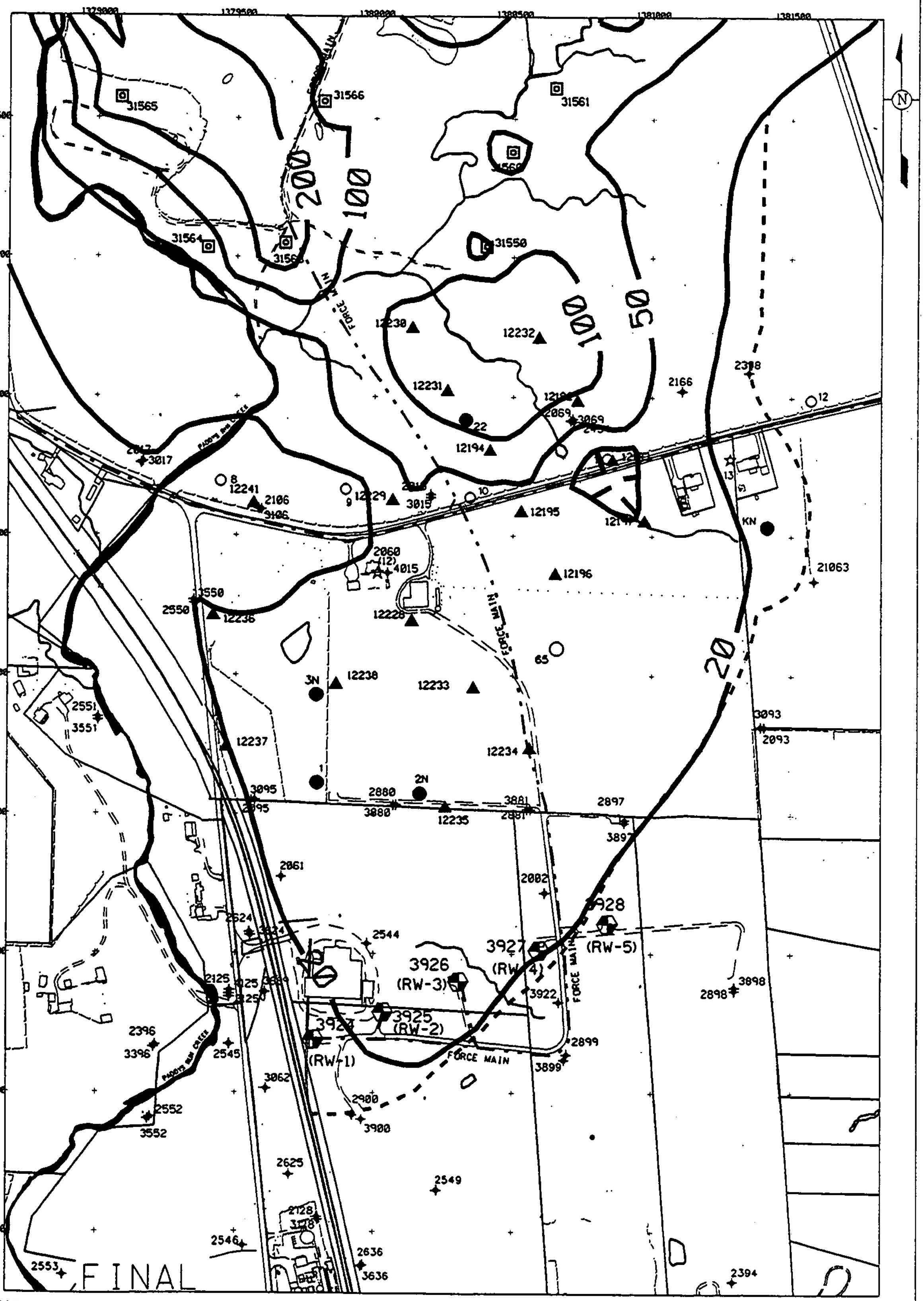
FIGURE E-49. FIVE YEAR CAPTURE ZONE FOR SCENARIOS A-5, A-6 AND A-8 (NO RETARDATION)



LEGEND:

- FEMP BOUNDARY
- FORCE MAIN
- MONITORING WELL
- HOMEOWNER WELL
- GEOPROBE LOCATION
- SOUTH PLUME EXTRACTION WELL
- SIMULATED INJECTION WELL
- SOUTH FIELD EXTRACTION WELL
- SIMULATED EXTRACTION WELLS
- MAXIMUM PLUME EXTENT
- URANIUM CONCENTRATION CONTOURS (ppb)

SCALE

350 175 0 350 FEET

FIGURE E-50. MAXIMUM EXTENT AND RESIDUAL PLUME AT THE END OF FY2003 - SCENARIO B-1

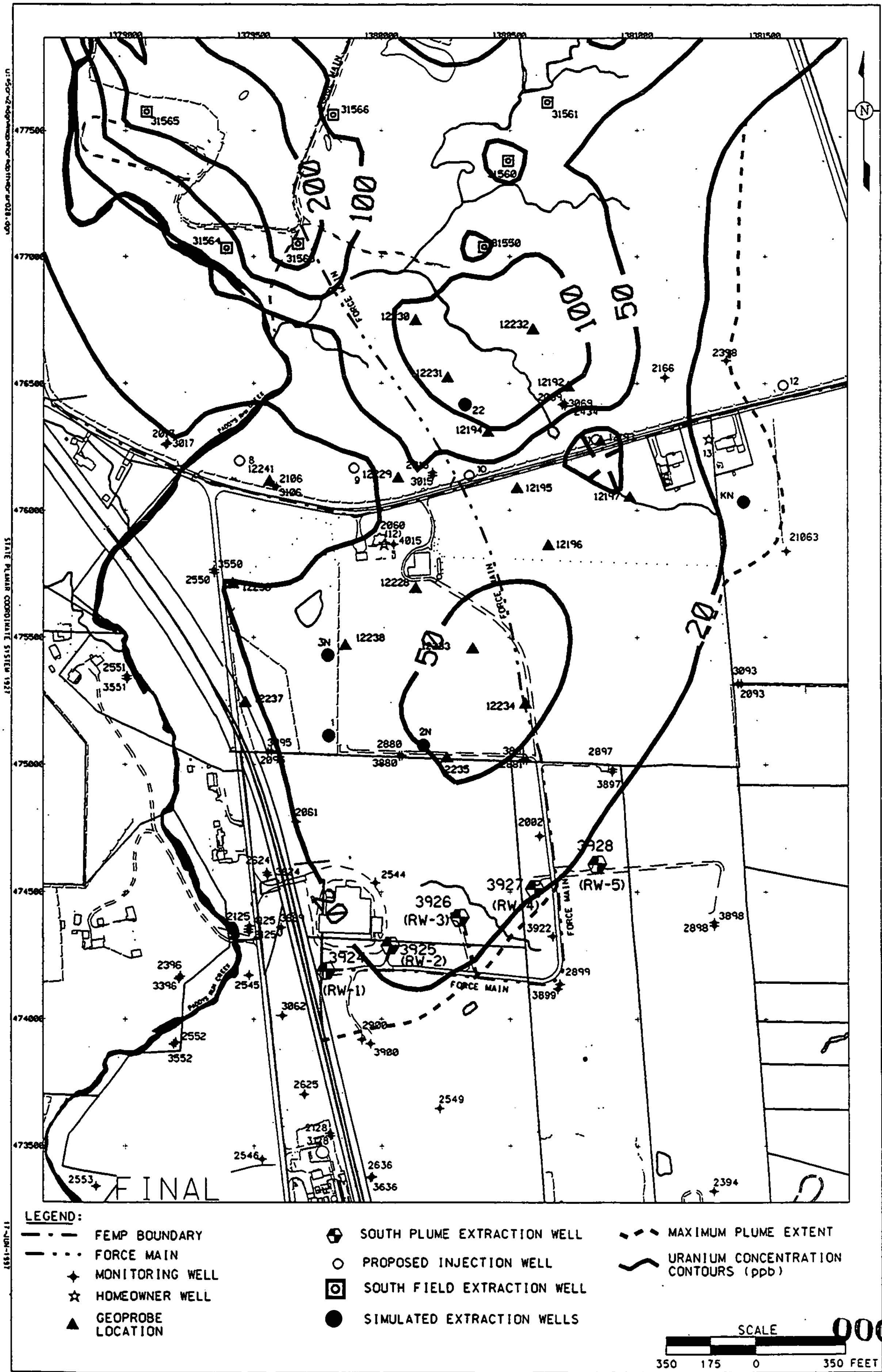


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FIGURE E-51. MAXIMUM EXTENT AND RESIDUAL PLUME AT THE END OF FY2003 - SCENARIO B-2

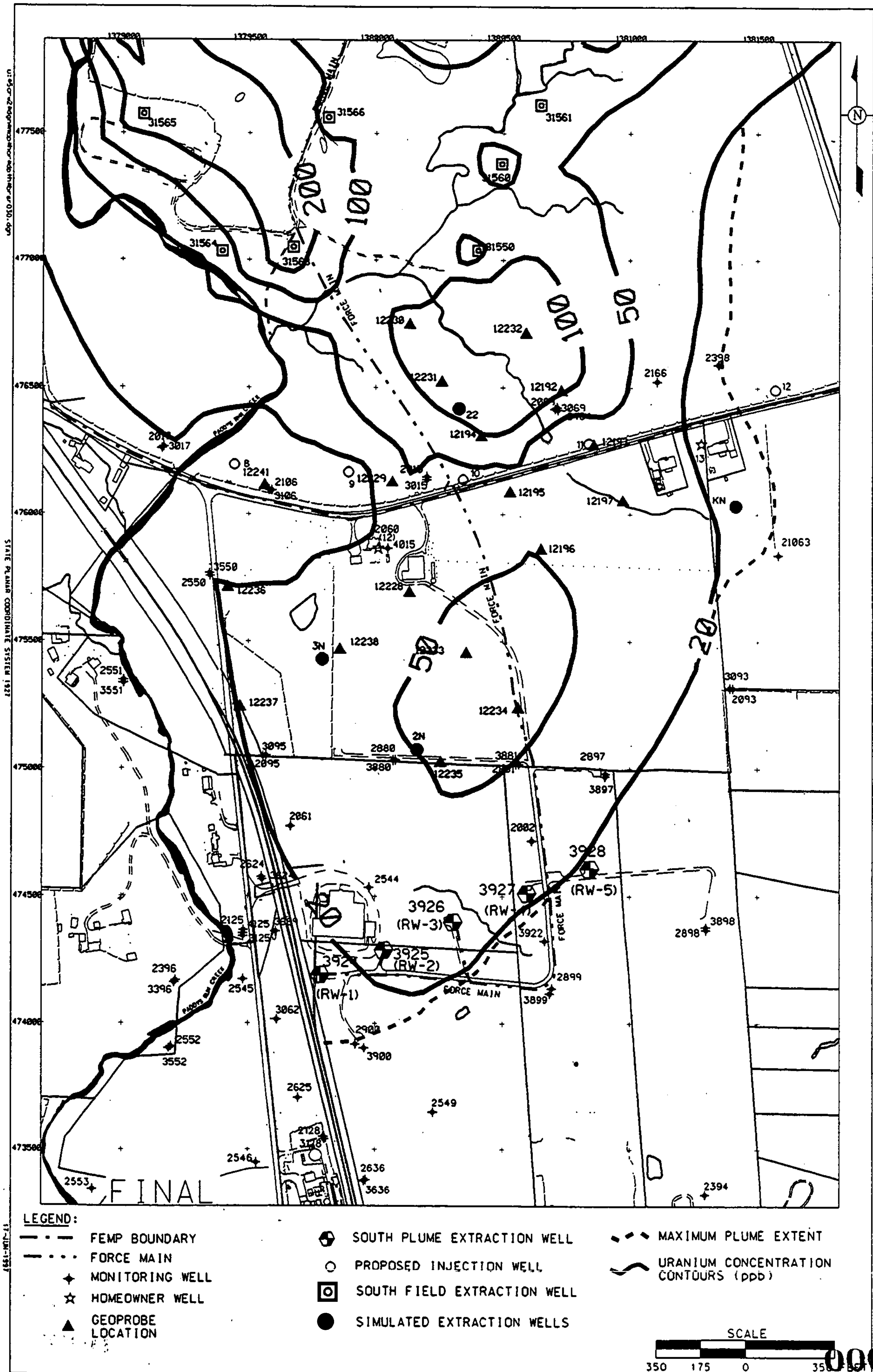

FIGURE E-52. MAXIMUM EXTENT AND RESIDUAL PLUME AT THE END OF FY2003 - SCENARIO B-3

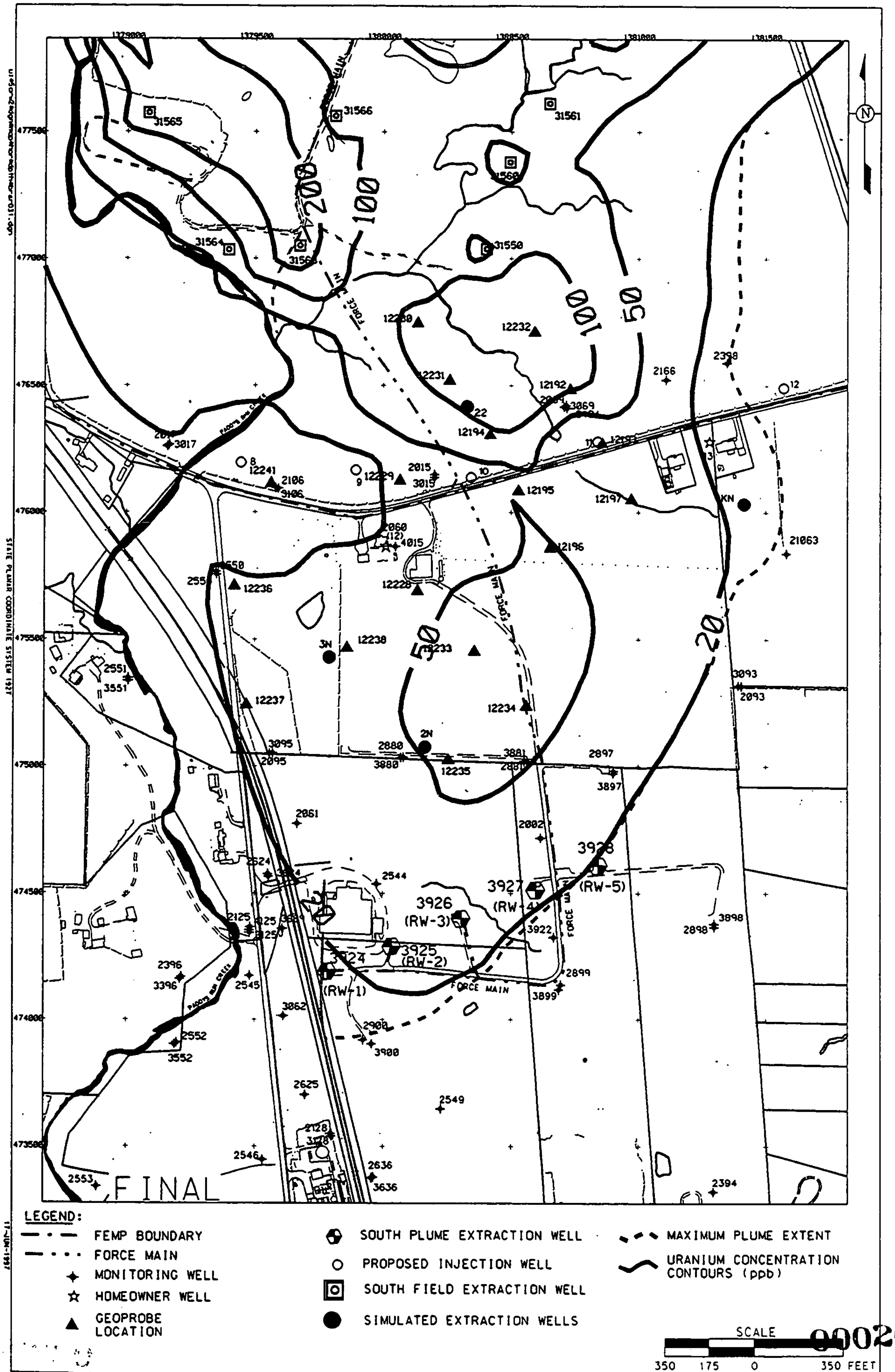

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FIGURE E-53. MAXIMUM EXTENT AND RESIDUAL PLUME AT THE END OF FY2003 - SCENARIO B-4

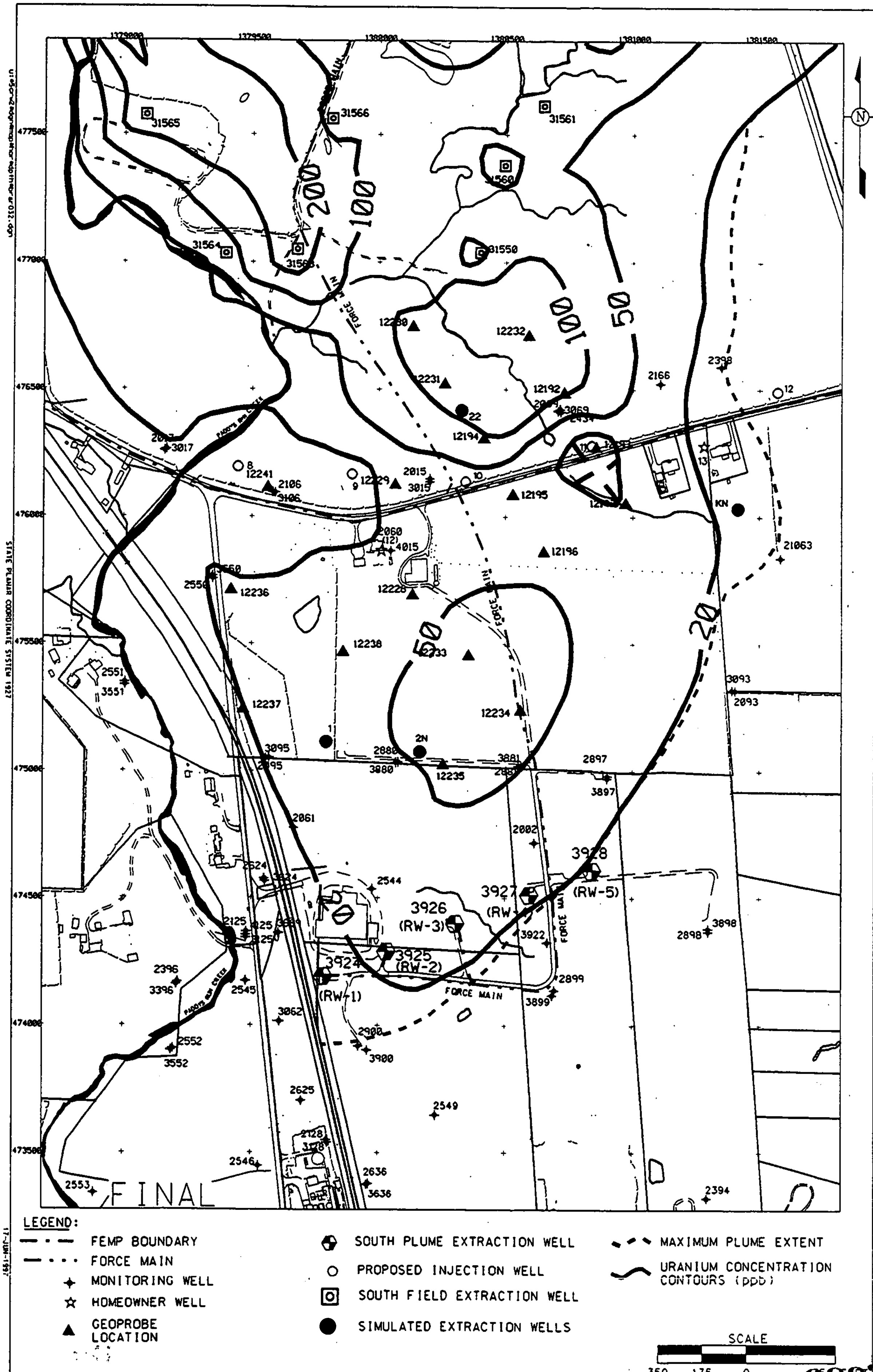

FIGURE E-54. MAXIMUM EXTENT AND RESIDUAL PLUME AT THE END OF FY2003 - SCENARIO B-5

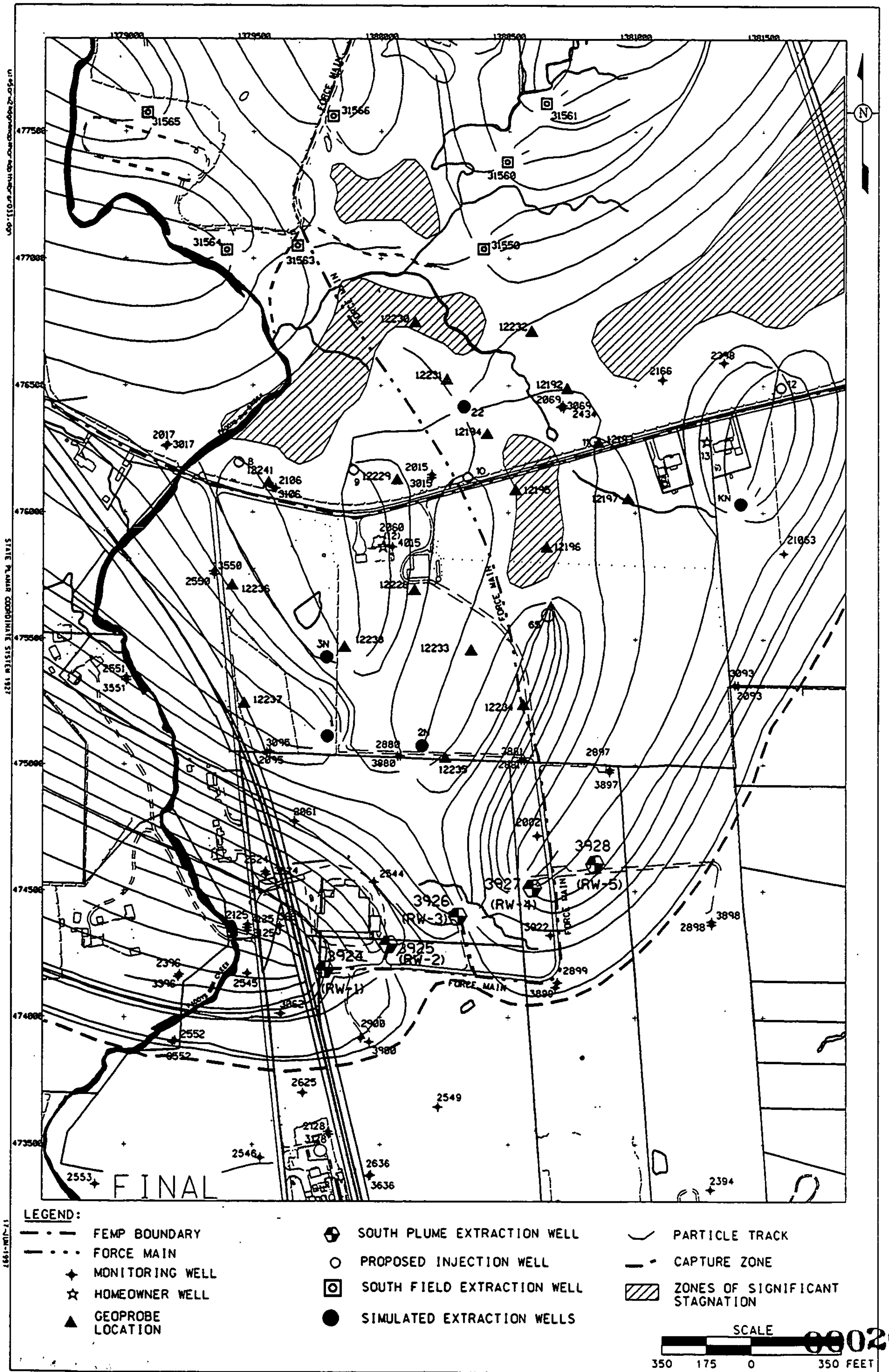

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FIGURE E-55. FIVE YEAR CAPTURE ZONE FOR SCENARIO B-1 (NO RETARDATION)

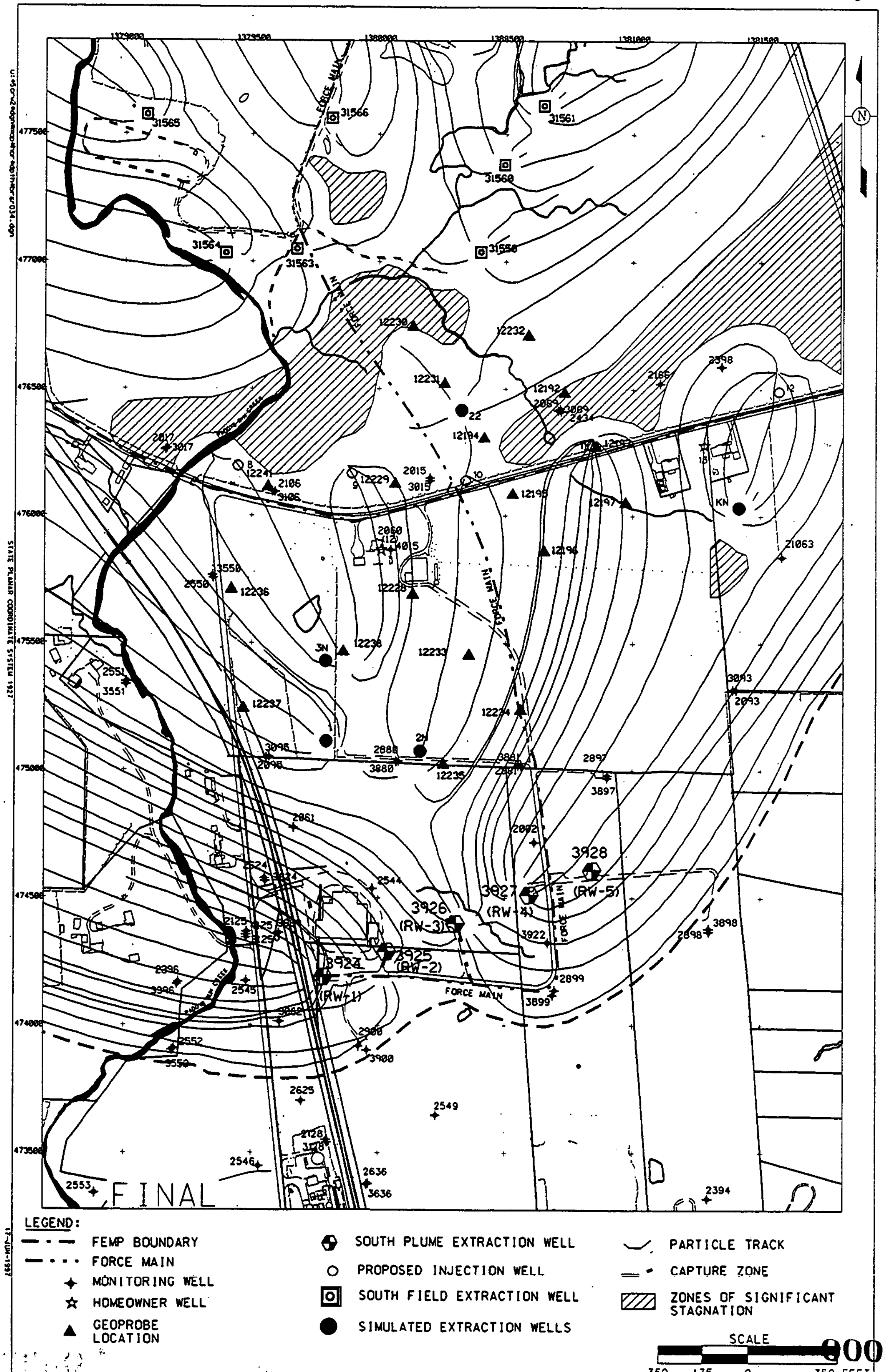

FIGURE E-56. FIVE YEAR CAPTURE ZONE FOR SCENARIO B-2 (NO RETARDATION)

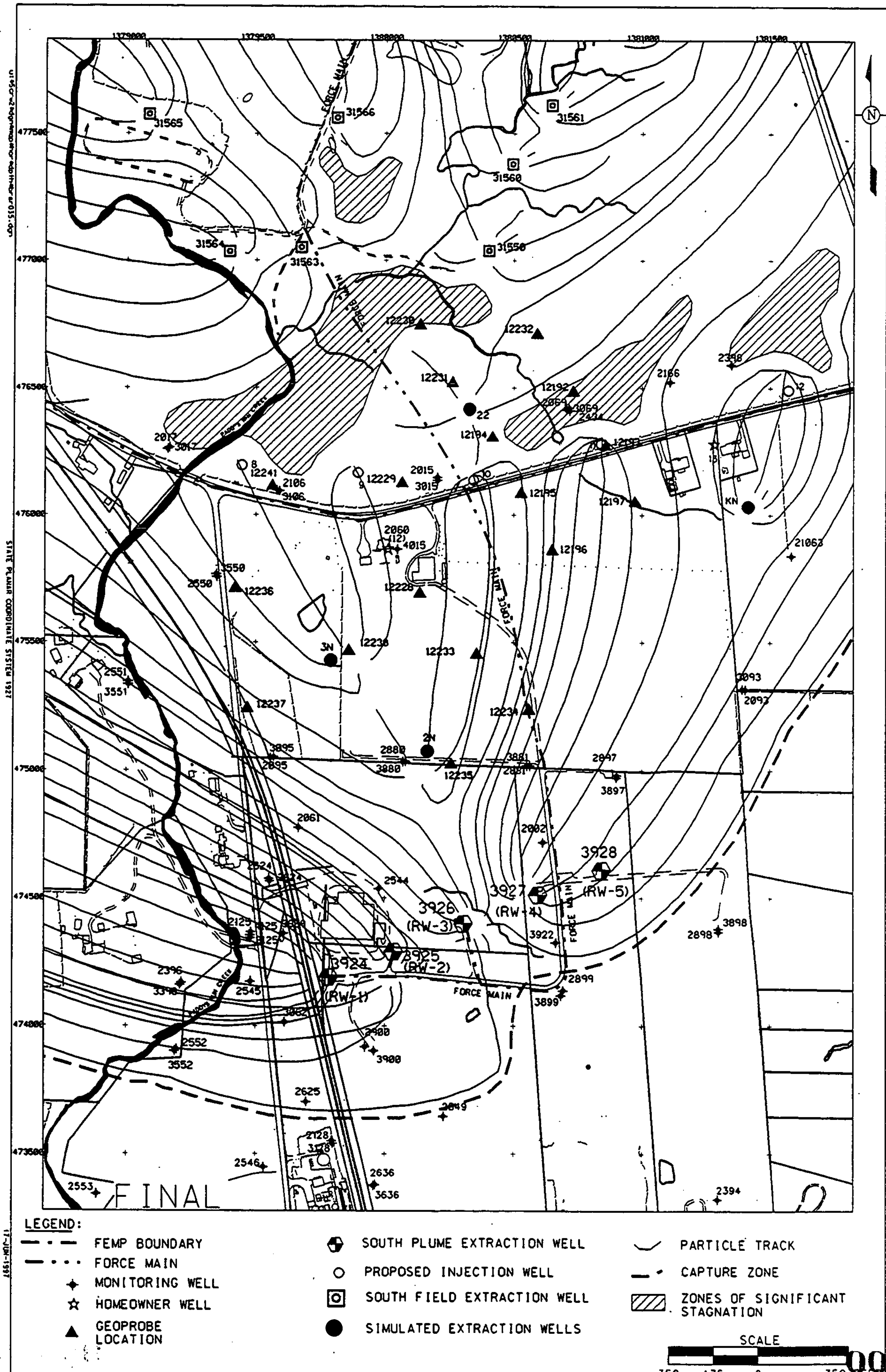

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FIGURE E-57. FIVE YEAR CAPTURE ZONE FOR SCENARIO B-3 (NO RETARDATION)

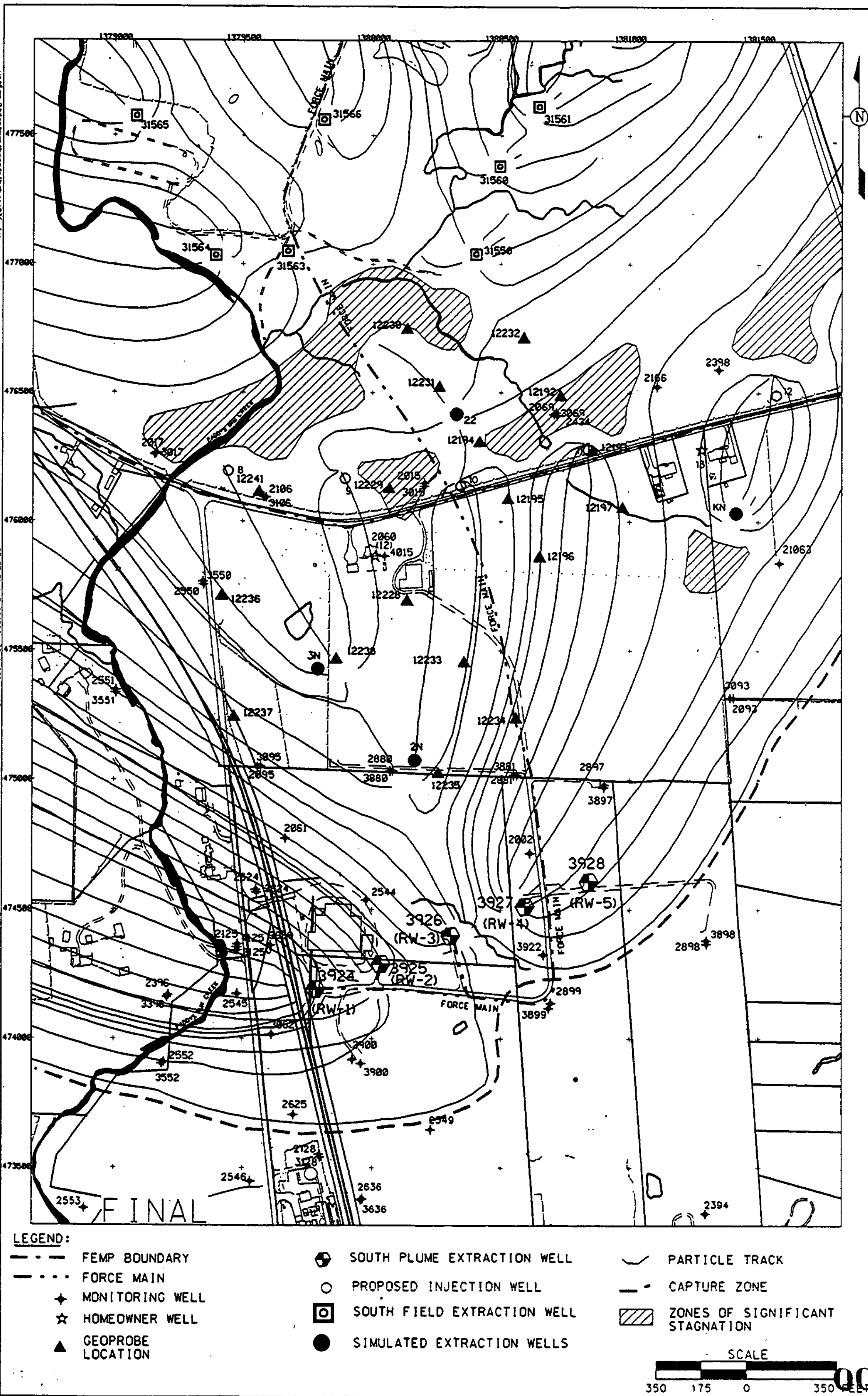

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FIGURE E-58. CAPTURE ZONE FOR YEARS 1999-2001, SCENARIO B-4 (NO RETARDATION)

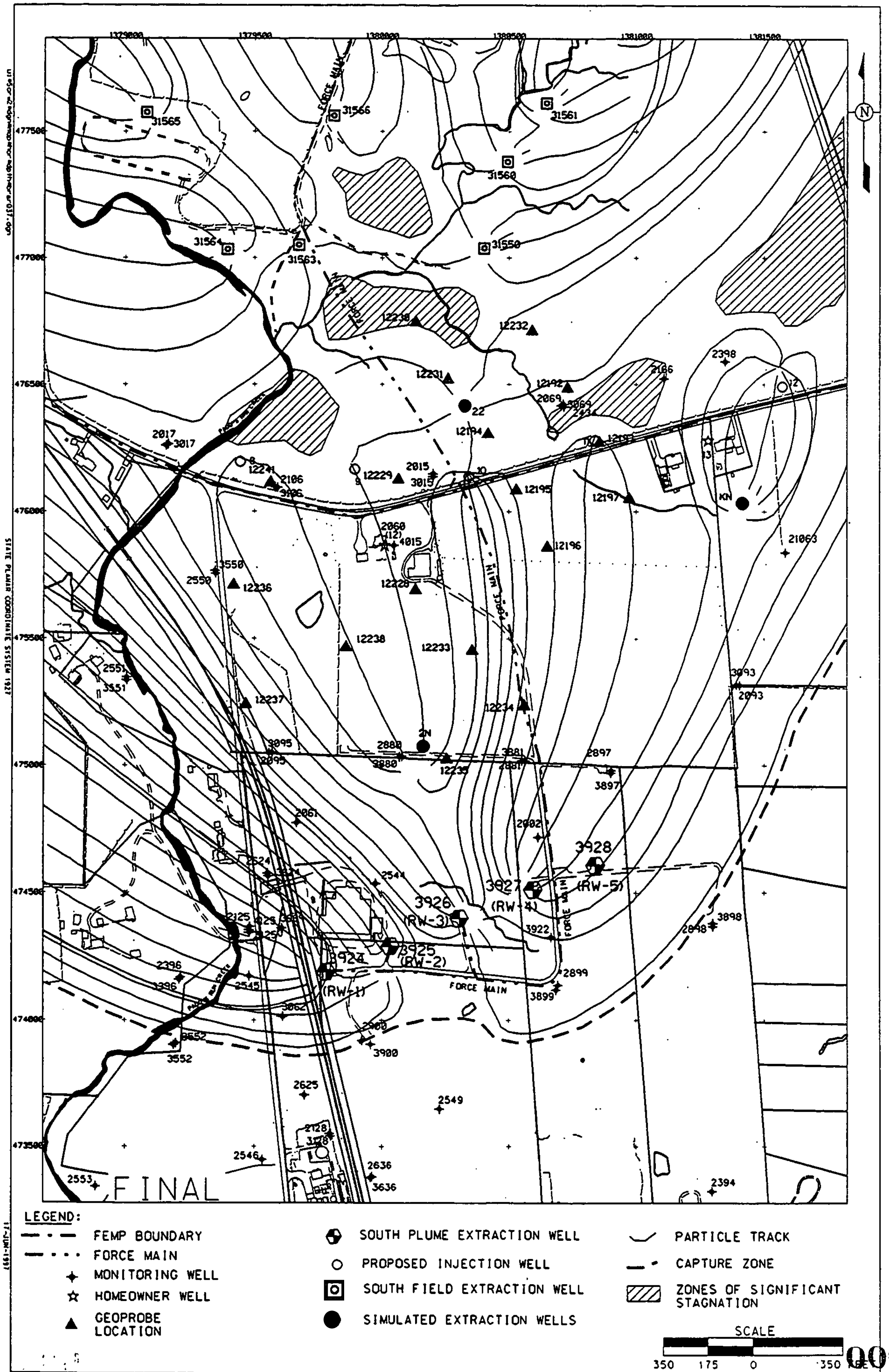

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FIGURE E-59. CAPTURE ZONE FOR YEARS 2002-2003, SCENARIO B-4 (NO RETARDATION)

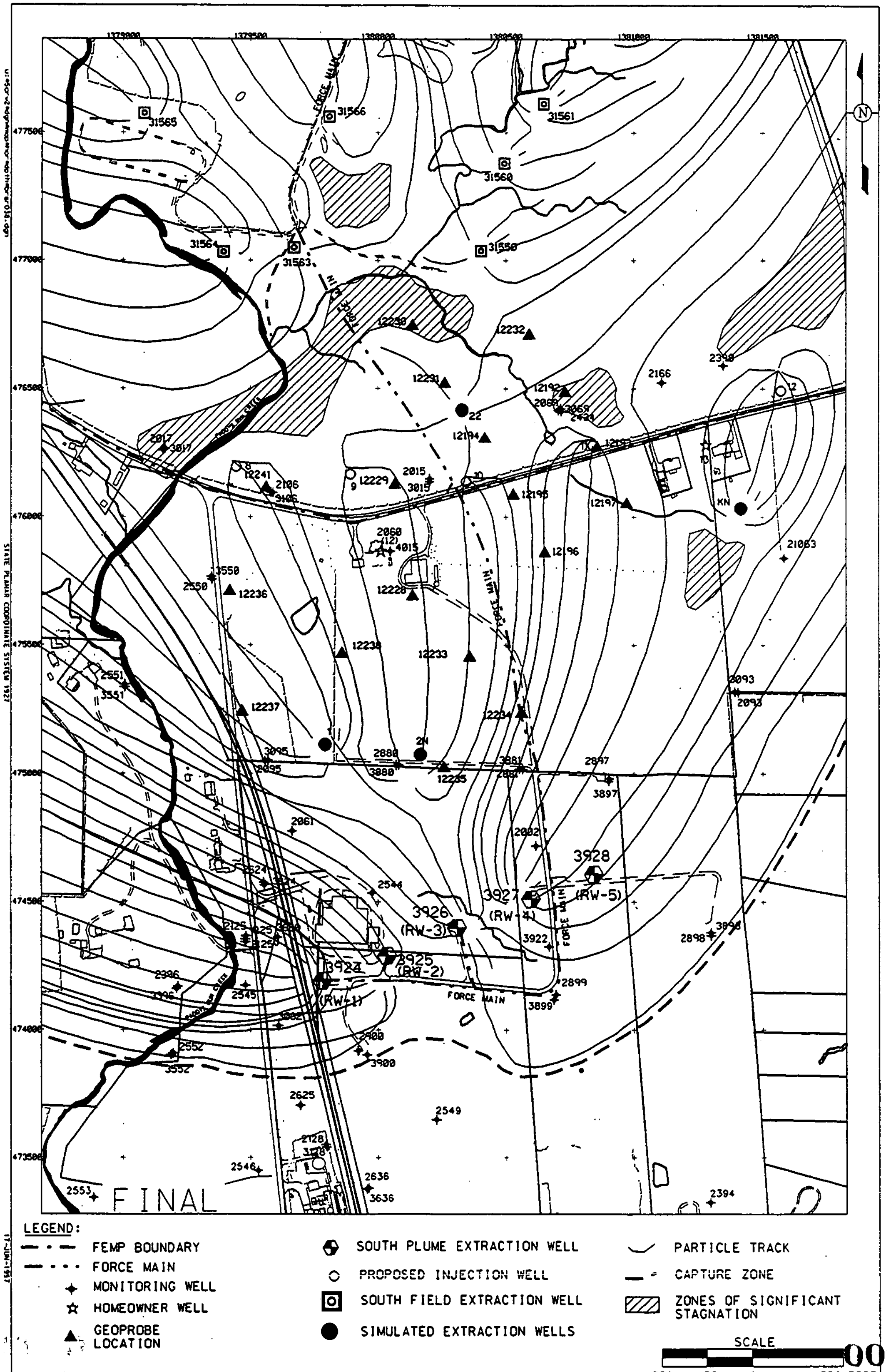

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FIGURE E-60. FIVE YEAR CAPTURE ZONE
FOR SCENARIO B-5 (NO RETARDATION)

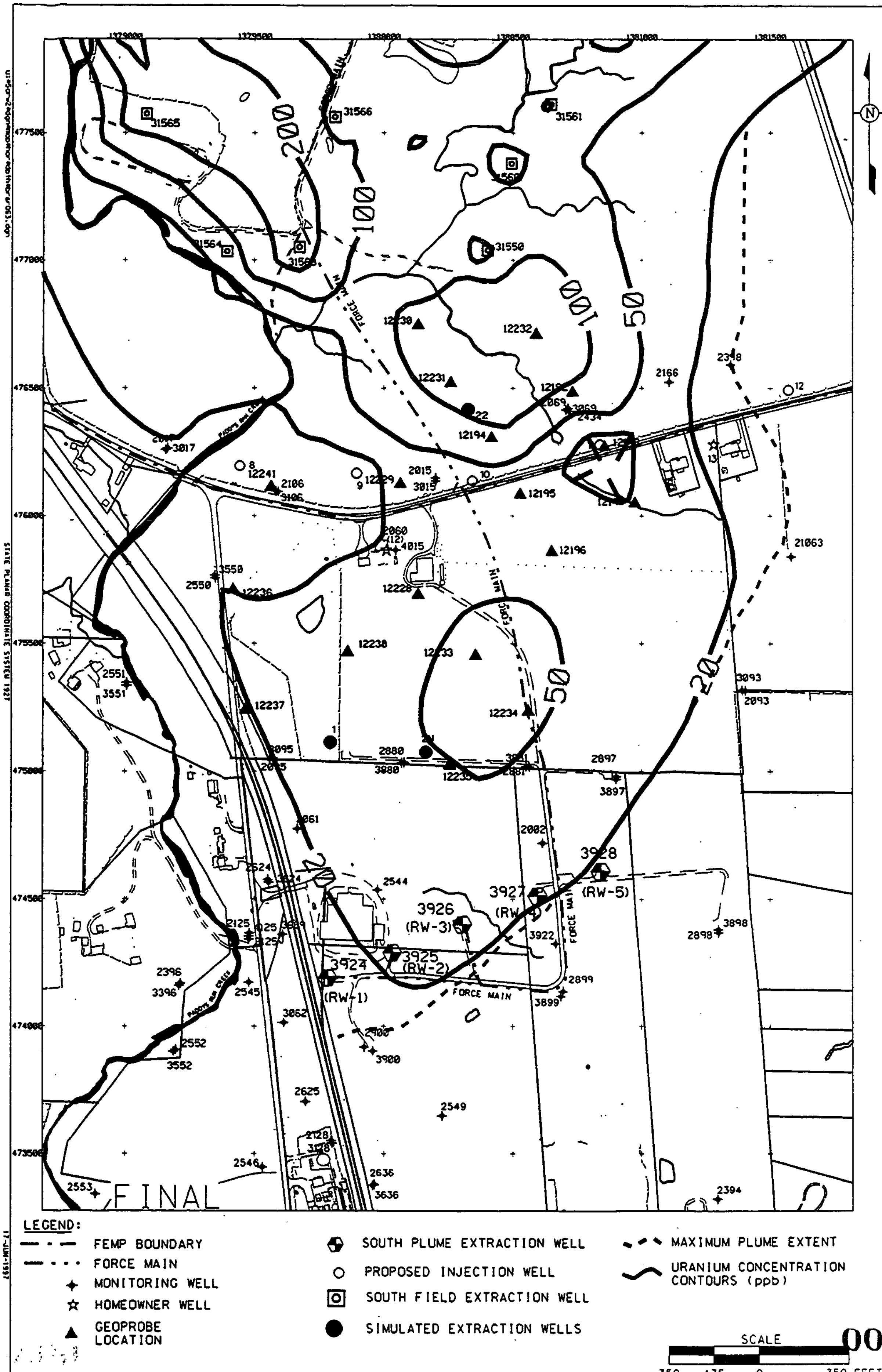

FIGURE E-61. MAXIMUM EXTENT AND RESIDUAL PLUME AT THE END OF FY2003 - SCENARIO C-1

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FIGURE E-62. MAXIMUM EXTENT AND RESIDUAL PLUME AT THE END OF FY2003 - SCENARIO C-2

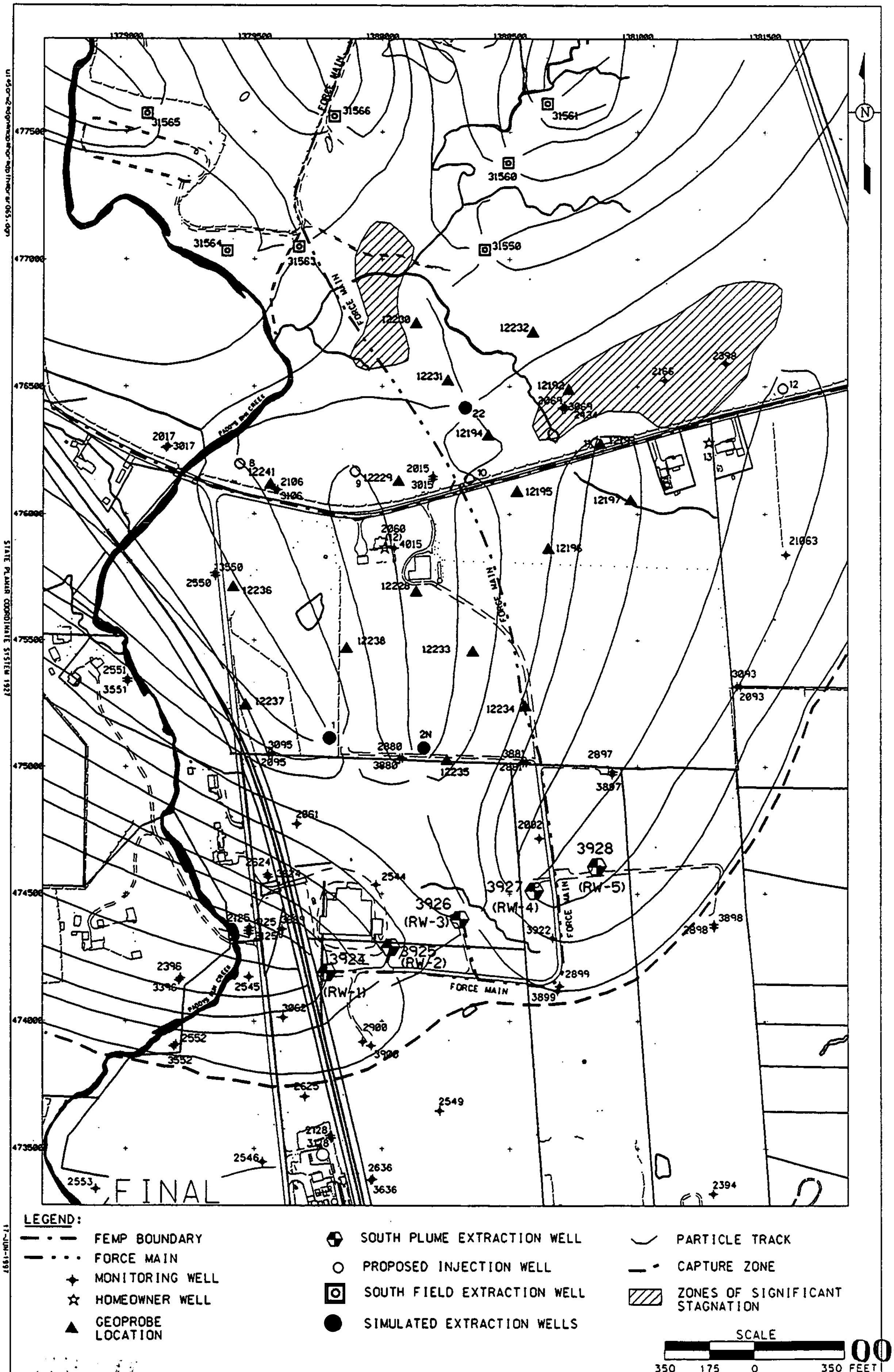

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FIGURE E-63. FIVE YEAR CAPTURE ZONE FOR SCENARIO C-1 (NO RETARDATION)

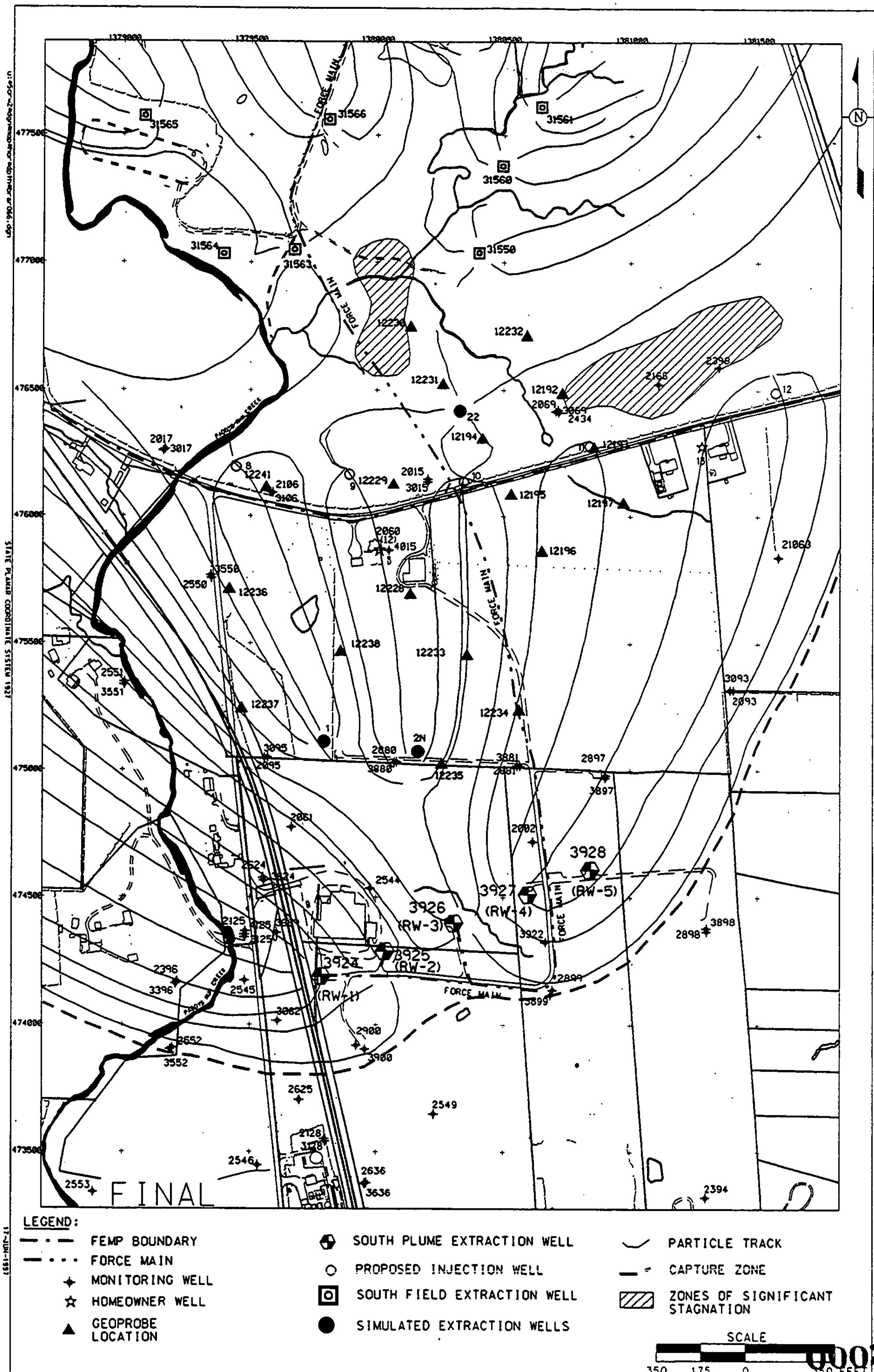

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FIGURE E-64. FIVE YEAR CAPTURE ZONE FOR SCENARIO C-2 (NO RETARDATION)

Appendix F

APPENDIX F

SUMMARY OF UNCERTAINTY ANALYSIS

F.1.0 INTRODUCTION

As described in Section 1.3 of this report, a number of factors cause uncertainty in the actual time and resources necessary to successfully complete the Great Miami Aquifer (GMA) restoration program at the FEMP. DOE, EPA, OEPA and other FEMP decision-makers need to fully understand the significance of the uncertainties in order to make well-informed decisions concerning how the program will be implemented both initially and at later stages of the cleanup.

The human factors (see Section 1.3.1) which can not be directly addressed in a quantitative uncertainty analysis were evaluated qualitatively when selecting the preliminary baseline strategy as discussed in Section 4.3.2. Following the selection of the preferred strategy using best available existing (i.e., pre-implementation) data and cost projections, uncertainty of the projected cleanup time of the selected baseline strategy was further analyzed. Impacts of the two major natural factors (i.e., hydraulic characteristics of the aquifer and geochemical conditions as described by the K_d parameter in the SWIFT model) were evaluated. The sensitivity of the projected system performance to aquifer hydraulic characteristics and geochemical conditions was first evaluated. The purpose of the sensitivity evaluation was to identify the critical parameters used in modeling to characterize these two factors. Critical parameters were identified based on parameter-specific uncertainties and expected impact to the modeling results within the parameter-specific uncertainty ranges. The critical parameters were then evaluated in the uncertainty analysis to quantify the ranges of potential cleanup time and cost. The overall approach for conducting the uncertainty analysis is presented in Figure F-1.

This appendix summarizes the sensitivity analysis using information from previous studies and provides a new quantitative uncertainty analysis. Model simulations of the recommended remedial system with bounding scenarios regarding the potential geochemical conditions were conducted in the uncertainty analysis.

F.2.0 EVALUATION OF PARAMETER SENSITIVITY

Various sensitivity and uncertainty analyses on the site-specific groundwater flow and contaminant fate and transport model parameters have been historically conducted during the groundwater model development and the Operable Unit 5 RI/FS

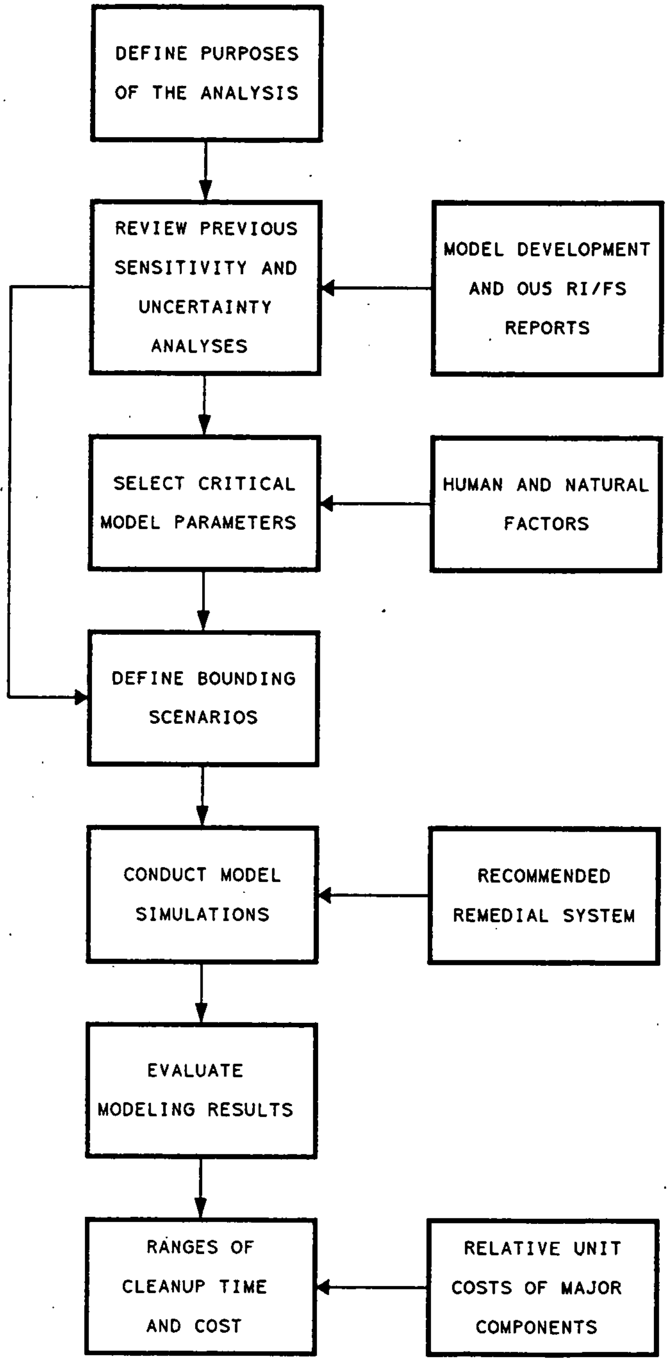

FIGURE F-1 OVERVIEW OF THE APPROACH

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processes. Information available from these analyses was reviewed first to identify critical parameters so the new uncertainty analysis on the recommended baseline remedial strategy can be focused on these critical parameters.

F.2.1 REVIEW OF PREVIOUS SENSITIVITY AND UNCERTAINTY ANALYSES

F.2.1.1 Model Development Process

During the model development process the following hydraulic and geochemical parameters were evaluated in an uncertainty analysis (DOE 1994):

- Horizontal hydraulic conductivity
- Horizontal/vertical hydraulic conductivity ratio
- Effective porosity
- Longitudinal dispersivity
- Hydraulic gradient
- Mixing depth
- Infiltration rate
- K_d value

The ECTran model (DOE 1993) was used to perform Monte Carlo simulation as a part of the sensitivity analysis of the model performance measure (i.e., exposure point concentrations) on these parameters. Results of these simulations supplement the simple-band SWIFT model sensitivity analysis by presenting the complete range of potential combinations of parameter values and corresponding exposure point concentrations using a probabilistic approach. The ECTran model simulations provide a general understanding of the sensitivity of the GMA model predictions to these tested parameters. In general, the analysis indicated that the predicted exposure point concentrations were more sensitive to K_d values than to all the hydraulic parameters.

A total of 17 sensitivity runs were subsequently performed using the SWIFT model in a simple-band sensitivity analysis. The purpose of these simulations was to assess each parameter individually in the SWIFT model. The general conclusions of the analysis indicated that uncertainty of the groundwater flow portion of the model (i.e., groundwater elevation, flow rate, and direction) is lower than the transport portion of the model (i.e., contaminant concentrations). The analysis of model uncertainty showed that defining key variables at extreme values impacts risk assessment performance measures (maximum concentration anywhere in the aquifer, and maximum concentration at the property line) in general, less than an order of magnitude. The ratio of potential actual value to the current best estimate was defined as the uncertainty factor for quantifying the uncertainty. Estimated range of the uncertainty factor for the maximum groundwater concentration was between 0.22 to 2.2 (Table 5.4-2, DOE 1994). The range of the uncertainty factor for the maximum fenceline groundwater concentration was between 0.28 to 1.43 (Table 5.4-2, DOE 1994).

F.2.1.2 Operable Unit 5 FS

A sensitivity analysis of aquifer cleanup time to geochemical conditions using the analytical model was presented in Attachment F.8.III, Appendix F of the Operable Unit 5 FS (DOE 1995a). The relationship between the "apparent" desorption K_d value and residual plume size after extracting the initial dissolved contaminant mass was first discussed. Impacts of "apparent" desorption K_d value, residual plume size, and groundwater flushing rate on aquifer cleanup time were then evaluated using an analytical model.

The analysis indicated that although higher desorption K_d values may potentially prolong the aquifer restoration time due to lower desorption rates, they can reduce the size of plume that will require long-term operation of the groundwater extraction system. Therefore, after terminating all the source loading and recovering the initial dissolved mass, the total pumping rate of the aquifer extraction system can be reduced and only focused on the smaller remaining plume which still has significantly high adsorbed-phase concentrations. To estimate additional time of extraction required after the initial dissolved-phase uranium mass has been recovered, the second part of the sensitivity analysis consisted of analytical model simulations to determine the relation between groundwater flushing rate and the required time to reach the groundwater cleanup level. Given an initial adsorbed-phase concentration of 5 mg/kg and a constant size of contaminated aquifer volume (i.e., 500 feet by 500 feet by 40 feet) used in the analysis, the additional extraction time required increased with increasing K_d value up to a point where further increases in K_d value began to reduce the time required. This phenomenon occurs because at some threshold value the portion of contaminant mass that is available to distribute into the dissolved-phase is insufficient to exceed the concentration-based groundwater cleanup level. For the assumed source condition, the maximum cleanup time resulted from a threshold K_d value around 100 L/kg. As expected, the cleanup time decreased with higher groundwater flushing rates. The maximum additional time required was about 15 years with a groundwater flushing rate of 1500 gpm for K_d values between 0 and 250 L/kg.

The SWIFT modeling approach using a K_d transition was first explored in Section F.7.7.4 of the Operable Unit 5 FS. However, correlation between timing of the K_d transition and termination of the surface source loading terms was not well defined in the preliminary modeling approach. No conclusive information was presented in the FS from these earlier model simulations. The lessons learned during the FS regarding simulating the K_d transition have been incorporated into the updated modeling approach presented in Appendix A of this report.

Sections F.7.7 and F.8.6 in Appendix F of the Operable Unit 5 FS (DOE 1995a) present sensitivity and uncertainty analyses conducted during the FS process. Geochemical conditions, hydraulic effects, and model limitations were all evaluated in detail. The following recommendation was presented in Section F.8.7.2.3:

"The actual contaminant desorption characteristics will affect the optimal aquifer remediation approach. The baseline geochemical conditions in the optimization study assumed a uniform uranium K_d value of 1.78 L/kg and fully reversible adsorption/desorption processes. These assumptions allow the maximum extent of the aquifer that may require continuous pumping, the maximum amount of uranium mass that needs to be recovered, and the potentially longest aquifer restoration time (due to the larger extent and mass need to be remediated with a limited extraction capacity) to be determined. Therefore, a conservative overall cost of aquifer restoration can be estimated for planning purposes.

However, the adsorption process is partially irreversible and the desorption process is usually slower as shown by the desorption batch tests for the South Field area aquifer soil samples. Based on results of the geochemical sensitivity analysis, higher K_d values (i.e., slower desorption) will require higher groundwater flushing rates in some localized areas which have significant solid-phase contaminant concentrations, in order to achieve cleanup in a reasonable time frame. When a K_d significantly higher than 1.78 L/kg is encountered, the extraction strategy will need to be adjusted during aquifer remediation. Because of the smaller residual plumes that will remain after extraction of the initial pore volume of the contaminated aquifer due to higher K_d value, available extraction capacity can then be concentrated in smaller areas to achieve higher groundwater flushing rates and achieve the same cleanup time frame (as demonstrated in the sensitivity analysis). Reinjection and pulsed pumping will also be considered to improve the mass removal efficiency. Therefore, the overall cost and remediation time frame for aquifer restoration will not be significantly affected when properly managed."

Although the Operable Unit 5 FS used a longer site-wide remediation schedule and did not include injection and additional off-property wells, the general conclusions of the sensitivity analyses conducted regarding important factors which will affect groundwater cleanup time and cost remain valid. Uncertainty of the original 27-year cleanup time frame due to the natural factors evaluated will not be significant when the extraction rate schedule can be properly adjusted according to the actual conditions encountered during the remediation.

F.2.2 <u>IDENTIFICATION OF THE CRITICAL FACTORS</u>

Given the FEMP's new 10-Year Site-Wide remediation schedule, the Baseline Remedial Strategy Report identifies a potentially shorter groundwater cleanup time frame using additional extraction wells and groundwater injection as part of the recommended baseline remedial strategy. Based on the best available information, the groundwater cleanup time as indicated by modeling simulations may be reduced to 10 years. However, the uncertainty of the achievable reduction of groundwater cleanup time and cost may be more significant than the uncertainty associated with the original overall cleanup time frame of 27 years. As mentioned earlier, although the potential cleanup time frame reduction will be very sensitive to the human factors (see Section 1.3.1), uncertainties associated with these factors can not be easily quantified. Therefore, the new quantitative uncertainty analysis only focuses on the natural factors.

Based on results of additional hydraulic tests conducted since the completion of the SWIFT GMA model development (DOE 1995c and DOE 1995d), the groundwater flow portion of the model usually matches the measured field conditions very closely. Because the recommended baseline remedial strategy does not increase hydraulic impacts to the GMA even when more extraction wells are included, the cleanup time frame will not be affected significantly by the uncertainties associated with the hydraulic parameters as concluded by the previous sensitivity analyses conducted during the RI/FS processes and the subsequent flow model validation results. The most critical natural factors which may affect the estimated cleanup time reduction are the geochemical parameters such as the K_d value and timing of the "apparent" K_d transition as defined in Appendix A. Although not evaluated in previous sensitivity analyses, timing of the "apparent" K_d transition is expected to have significant

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impacts on the cleanup time. Therefore, these two geochemical parameters were selected for further evaluation in the new quantitative uncertainty analysis.

F.3.0 BOUNDING SCENARIOS OF THE UNCERTAINTY ANALYSIS

For this uncertainty analysis the K_d values and timing of K_d transition described in Appendix A for all the model simulations presented in this report except the uncertainty analysis was termed the baseline scenario. In the baseline scenario, the "apparent" adsorption and desorption K_d values were 1.78 and 17.8 L/kg, respectively. Local transition between these two K_d values was assumed to occur after termination of the localized source loading terms (based on the new 10-Year Site-Wide Remediation Plan) and extraction of one additional pore volume from each local contaminated portion of aquifer. Under the baseline remedial strategy, it will only take a few months to extract one pore volume from the contaminated portion of aquifer covered by a remedial system module.

Bounding scenarios which have different combinations of K_d values and timing of K_d transition than the baseline scenario were defined to bracket the plausible range of potential conditions. Based on information obtained from the previous uncertainty analyses, the following three bounding scenarios were developed:

- No-Transition Scenario - Assuming that the initial "apparent" desorption K_d value of 1.78 L/kg throughout the remediation.
- No-K_d Scenario - Assuming no adsorption/desorption process and all the initially adsorbed mass will not dissolve during remediation.
- Delayed Transition Scenario - Assuming that the K_d transition will not occur immediately after the source termination and extraction of one additional pore volume.

The No-Transition Scenario should provide an upper bounding estimate of the cleanup time estimate and the No-K_d Scenario should provide a lower bounding estimate of the cleanup time estimate. Together with the baseline scenario, cleanup time frames under these scenarios should provide sufficient information regarding cleanup time uncertainty of a remedial system.

The recommended baseline remedial strategy, as presented in Section 5.2, was then simulated with each of these bounding scenarios in the quantitative uncertainty analysis of the cleanup time frame. In order to simplify the analysis, only minor modifications to the original extraction/remediation schedule using the wells included in the recommended baseline strategy were considered in these simulations. However, during actual operation further improvements of the system performance by further adjusting the extraction/injection rate schedule will be possible.

F.4.0 MODELING RESULTS

F.4.1 CLEANUP TIME RANGE

In order to estimate the uncertainty due to geochemical conditions alone, the model simulations only focused on the South Field and South Plume areas. The modeling results for each scenario revealed the following:

- The simulated cleanup time for the No-Transition Scenario is about 20 years.
- The simulated cleanup time for the No-K_d Scenario is within one year after the local surface source remediation was assumed to be completed. For example, if South Field surface source-area remediation takes 7 years, the groundwater cleanup time will be within 8 years.
- The simulated cleanup time of the Delayed-Transition Scenario is within one year after the K_d transition, if the transition occurs more than one year after termination of the local source-area loading. For example, because the South Field surface source remediation is scheduled to be completed in 7 years under the 10-Year Site-Wide Remediation Plan, if the "apparent" K_d transition occurs at the end of 8th year, the groundwater cleanup time will be within 9 years.

The estimated range of groundwater cleanup time in the South Field and South Plume areas due to uncertainty regarding geochemical conditions alone is between 8 to 20 years.

Although not specifically evaluated, the last two conclusions should also apply to the Waste Pit and production area portion of the plume. Under the No-Transition Scenario the cleanup times for the Waste Pit and production area should be less than 20 years, because of the lower initial concentrations and smaller plume than the South Field and South Plume areas. It was assumed that the source remediation in the Waste Pit and the production areas will be completed within 10 years under the 10-Year Site-Wide Remediation Plan it will take a few more months to extract one additional pore volume from the contaminated portion of the aquifer. Therefore, based on all the findings, the range of the overall Great Miami Aquifer groundwater cleanup time using the recommended baseline remedial strategy, considering uncertainty, should be between 10 to 20 years.

It is also important to note that the cleanup time range discussed above assumes that the planned groundwater injection wells will be successfully operated and sufficiently maintained at the level simulated throughout the aquifer remediation. If this assumption does not materialize, the actual groundwater cleanup time may not be significantly shorter than the 27 years time frame estimated in the Operable Unit 5 FS. It is difficult to predict the possibility of long-term success for the groundwater injection operation. The full-scale Groundwater Injection Demonstration along the FEMP southern fenceline to be conducted in 1998 will provide real data for re-evaluating long-term feasibility, operation and maintenance requirements, and effects of groundwater injection.

F.4.2 COST RANGE

Using the relative unit costs presented in Table 4-9, the overall cost of the aquifer remediation will be between 140 to 250 relative cost units (each unit is $500,000). The difference between the lower and upper bounds primarily includes 10 years of groundwater treatment operation and monitoring and reporting activities after all the other FEMP source remedial activities are completed.

REFERENCES

U.S. Department of Energy, 1993, "Development and Application of the ECTran Model to Support the RI/FS at the FEMP," Fernald Environmental Management Project, DOE, Fernald Field Office, Cincinnati, OH.

U.S. Department of Energy, 1994, "SWIFT Great Miami Aquifer Model - Summary of Improvements Report," Fernald Environmental Management Project, DOE, Fernald Field Office, Cincinnati, OH.

U.S. Department of Energy, 1995a, "Feasibility Study Report for Operable Unit 5," Final, Fernald Environmental Management Project, DOE, Fernald Area Office, Cincinnati, OH.

U.S. Department of Energy, 1995b, "Remedial Investigation Report for Operable Unit 5," Final, Fernald Environmental Management Project, DOE, Fernald Area Office, Cincinnati, OH.

U.S. Department of Energy, 1995c, "South Field Pumping Test Report," Fernald Environmental Management Project, DOE, Fernald Area Office, Cincinnati, OH.

U.S. Department of Energy, 1995d, "South Field Injection Test Report," Fernald Environmental Management Project, DOE, Fernald Area Office, Cincinnati, OH.

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Appendix G

APPENDIX G

GEOPROBE SAMPLING RESULTS
AND URANIUM PLUME INTERPRETATIONS

G.1.0 BACKGROUND

This appendix reports uranium concentration profiles for 19 different locations (Figure G-1) and presents an updated maximum total uranium plume map using the new Geoprobe™ data in conjunction with data collected from monitoring wells. The uranium concentration profiles were defined from the analysis of groundwater samples which were collected using a Geoprobe™ mill-slotted well point sampler. The sampling took place between October 1996 and May 1997.

The Restoration Area Verification Sampling Program Project Specific Plan was the controlling document for the Geoprobe™ sampling. The draft work plan, which proposed six sampling locations, was issued to the EPA and OEPA in October of 1996. DOE began the geoprobe work while comments on the draft work plan were being resolved. The draft final work plan was issued to the EPA and OEPA in January of 1997.

At the time that the Project Specific Plan for the Geoprobe™ sampling was written, work was proceeding on the design of a restoration system for remediating the Great Miami Aquifer. A strategy for remediating the ≥ 20 μg/L total uranium plume in the aquifer was presented in the OU5 Feasibility Study (DOE 1995) and approved as the remedy of choice in the OU5 Record of Decision (DOE 1996). The approved remedy calls for a pump-and-treat remediation and the commitment to investigate the use of groundwater injection as a means of accelerating or improving the results of the pump-and-treat remedy. Geoprobe™ sampling was proposed for an area of the plume around Monitoring Wells 2434 and 3069 because monitoring information collected for the South Plume DMEPP indicated that a portion of the 20 μg/L total uranium plume may be migrating between the FEMP Type 2 and Type 3 fixed monitoring well depths..

West of the 2434 and 3069 area, a large portion of the ≥ 20 μg/L total uranium plume extends south of the FEMP property. East of the 2434 and 3069 area, a small lobe of the 20 μg/L total uranium plume also extends south of the FEMP property (Figure G-2). In the immediate area around Monitoring Wells 2434 and 3069, the leading edge of the 20 μg/L total uranium plume appears to move deeper into the aquifer (Figure G-3). An explanation for this observation was presented in the South Plume Evaluation Report, for January, 1996 to June 30, 1996 (DOE, 1996). Recharge from a nearby drainage ditch appeared to be pushing the higher uranium concentrations deeper into the aquifer. It was possible that a portion of the 20 μg/L plume was migrating between the FEMP's Type 2 and Type 3 Monitoring Wells. If the leading edge of the plume extended further than what had been previously characterized, then the restoration system design might need to be modified to provide for the deeper plume depths and additional plume area.

As explained below, sampling at the six locations identified in the Project Specific Plan provided enough data to firmly establish the location of the leading edge of the 20 μg/L total uranium plume in the area around Monitoring Wells 2434 and 3069. Uranium concentration data from Geoprobe™ Location 12195 (which is southwest of Monitoring Wells 2434 and 3069) were higher than expected, indicating that the leading edge of the 20 μg/L total uranium plume had migrated further than had been previously mapped. To establish where the leading edge was located required a second Phase of Geoprobe™ sampling. Additional questions raised by the interpretation of data from the second phase established the need for a third phase of Geoprobe™ sampling (Figure G-1).

Presented below in Sections 2,3, and 4 are the results of each of the three phases of Geoprobe™ sampling. Section 5 presents an updated characterization of the 20 μg/L total uranium plume in which both maps and cross sections are presented.

G.2.0 PHASE I GEOPROBE™ RESULTS.

Six locations (12192, 12193, 12194, 12195, 12196, and 12197) were sampled during Phase I. These are the six locations which were originally proposed in the Restoration Area Verification Sampling Program Project Specific Plan (Figure G-1). The six locations were selected to determine the leading edge of the 20 μg/L total uranium plume in the area of Monitoring Wells 2434 and 3069. Sampling of the six locations began on October 23, 1996 and ended on December 28, 1996. Results for the six locations are presented in Tables G-1 to G-6, Figures G-4 to G-9, and highlighted below.

Locations 12192, 12193, and 12197, running from the northwest to the southeast respectively, are located east of Monitoring Wells 2434 and 3069. Sampling at all three locations reached a depth of 100 feet below the water table, with samples collected every ten feet, starting 1 foot below the water table. Results are presented in Tables G-1 to G-3, and Figures G-4 to G-6. Results indicate that the top of the 20 μg/L total uranium plume is migrating 20 feet to 30 feet below the water table rather than at the water table. The highest concentrations (331 μg/L at location 12192, 34 μg/L at

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location 12193, and 1 μg/L at location 12197) were measured at depths of 50 feet, 40 feet, and 1 foot below the water table respectively. The leading edge of the 20 μg/L total uranium plume is located slightly south of the FEMP property line between locations 12193 and 12197.

Locations 12194, 12195, and 12196, running from the northwest to the southeast respectively, are located west of Monitoring Wells 2434 and 3069. Sampling at locations 12194, 12195, and 12196 reached a depth of 100 feet, 70 feet, and 80 feet below the water table respectively. Samples were collected every ten feet, beginning 1 foot below the water table. Results are presented in Tables G-4 to G-6, and Figures G-7 to G-9. Results indicate that the leading edge of the 20 μg/L total uranium plume is located farther southeast than previously thought. Total uranium concentrations at location 12195 reached 300 μg/L. Prior to the collection of Geoprobe™ samples, it was thought that the total uranium concentration at this location was below or very near 20 μg/L. The highest total uranium concentration measured at location 12196 (1.6 μg/L) indicates that the leading edge of the 20 μg/L total uranium plume is located between locations 12195 and 12196.

The higher than expected total uranium concentration measured at location 12195 suggested that area of the plume southwest of location 12195 may be larger than previously characterized. Therefore, a second phase of geoprobe sampling was initiated to address this question.

G.3.0 PHASE II GEOPROBE™ RESULTS

Eight locations (12228, 12229, 12230, 12231, 12232, 12233, 12234, and 12235) were sampled during Phase II. The eight locations were selected to address two data questions concerning the 20 μg/L total uranium plume: 1) What is the highest total uranium concentration north and northwest of Monitoring Wells 2434 and 3069 and south of the Storm Sewer Outfall Ditch?; and 2) Does the leading edge of the 20 μg/L total uranium plume, west and southwest of location 12195, extend out farther to the southeast than was currently mapped at the time? Locations 12230, 12231, and 12232 were selected to answer the first question. Locations 12228, 12229, 12233, 12234, and 12235 were selected to address the second question (Figure G-1). Sampling of the eight locations began on December 31, 1996 and ended on February 27, 1997. Results for the eight locations are presented in Tables G-7 to G-14, Figures G-10 to G-17, and highlighted below.

Locations 12230, 12231, and 12232 (located north and northwest of Monitoring Wells 2434 and 3069) indicate that the top of the 20 μg/L total uranium plume is at the water table and that the highest total uranium concentration measured was in good agreement with concentrations previously mapped for the area. Results are presented in Tables G-7 to G-9 and Figures G-10 to G-12.

Locations 12228, 12233, and 12234, running northwest to southeast respectively, are located southwest of location 12195 (Figure G-1). Sampling reached a depth of 90 feet, 70 feet, and 70 feet below the water table respectively. Samples were collected every 10 feet, starting 1 foot below the water table. Results are presented in Tables G-10 to G-12, and Figures G-13 to G-15. Results indicate that the top of the 20 μg/L total uranium plume is located more than 10 feet below the top of the water table at all three locations indicating that Type 2 well screens may not be properly positioned to monitor the movement of the plume in this area. The highest concentrations (96 μg/L at location 12228, 123 μg/L at location 12233, and 53 μg/L at location 12234) were measured a depths of 30 feet, 20 feet, and 20 feet below the top of the water table respectively. The leading edge of the 20 μg/L total uranium plume is located east of location 12234, indicating that the leading edge of the total uranium plume is farther east than had been previously mapped for this area.

Location 12235 is located southwest of location 12234 (Figure G-1). Sampling at this location reached a depth of 70 feet below the top of the water table. Results are presented in Table G-13 and Figure G-16. Results indicate that the top of the 20 μg/L total uranium plume is located more than 10 feet below the top of the water table indicating that a Type II well screen may not be properly positioned to monitor the movement of the plume in this area. The highest concentration measured (127 μg/L) was measured at a depth of 20 feet below the top of the water table. The leading edge of the 20 μg/L total uranium plume is located east of location 12235, indicating that the leading edge of the total uranium plume is farther east than had been previously mapped for this area using Type 2 and Type 3 monitoring data.

Location 12229 is located west of location 12195. Sampling at this location reached a depth of 70 feet below the top of the water table. Results are presented in Table G-14 and Figure G-17. Results indicate that the top of the 20 μg/L total uranium plume is located at the water table. The highest concentration measured (99 μg/L) was measured at a depth of 10 feet below the top of the water table. Prior to the collection of the Geoprobe™ samples, the concentration of the plume in this area was believed to be approximately 150 μg/L using Type 2 and Type 3 monitoring well data.

The higher than expected total uranium concentrations measured at locations 12228, 12233, 12234, and 12235, and the depth of the top of the total uranium plume being more than 10 feet below the top of the water table, raised the following question concerning the characterization of the total uranium plume: How large is the 100 μg/L total uranium plume south of Willey Road? A third Phase of Geoprobe™ sampling was conducted to address this question.

G.4.0 PHASE III GEOPROBE™ RESULTS

Five locations (12236, 12237, 12238, 12241, and 12265) were sampled during Phase III. The five locations were selected to address two questions concerning the total uranium plume: 1) How large is the 100 μg/L total uranium plume south of Willey Road? 2) Is the eastern edge of the 20 μg/L total uranium plume, north of Willey Road properly located.

To answer the first question, four locations were sampled to a depth of 100 feet, 80 feet, 80 feet and 90 feet below the water table respectively. The first sample was collected 1 foot below the water table, with subsequent samples collected every ten feet. Results are presented in Tables G-15 to G-18 and Figures G-18 to G-21. Results indicate that the 100 μg/L total uranium plume south of Willey Road is larger than previously mapped.

One location (12265) was sampled to address the 2nd question. Total uranium concentrations were all well below 20 μg/L indicating that the eastern edge of the 20 μg/L total uranium plume is properly located, as shown in Figure G-23.

G.5.0 20 Mg/L TOTAL URANIUM PLUME INTERPRETATIONS

Data collected from the 19 Geoprobe™ locations were used to produce an updated maximum total uranium plume map (Figure G-23, updated total uranium plume map) and to construct eight cross-sections based on the updated total uranium plume map. The cross sections with location maps are presented in Figures G-24 to G-31.

The updated total uranium plume map (Figure G-23) was prepared using:

- The maximum total uranium concentration measured at each of the 19 different Geoprobe™ locations described above;

- The maximum total uranium concentration measured at the Southfield recovery wells during installation of the wells using a Hydropunch™ sampling tool; and

- The maximum total uranium concentration measured in Type 2 or Type 3 monitoring wells if no Geoprobe™ or Hydropunch™ data was available for the well or if the well data indicated higher uranium concentrations.

The uranium concentration values reported on Figure G-23 are averaged over different sampling lengths. Groundwater samples collected from Type II wells are averaged over 10 to 15 feet. Groundwater samples collected from Type III wells are averaged over 10 feet. Groundwater samples collected using the Geoprobe™ sampler are averaged over 2 feet and the groundwater samples collected using the Hydropunch™ sampler are averaged over 4 feet. The samples that are averaged over longer sampling intervals have a greater chance of being biased toward lower concentrations and the samples averaged over shorter sampling intervals have a greater chance of being biased toward higher concentrations.

Cross section A-A' (Figure G-24) is oriented west to east and extends through the total uranium plume along Willey Road. The eastern half of the cross section illustrates the effect that recharge is having on the migration of the plume. The top of the 20 μg/L total uranium plume is located approximately 30 to 40 feet below the top of the water table. The plume is also very thin in this area, approximately 10 to 20 feet thick, compared to the west where the plume is approximately 50 feet thick.

Cross section B-B' (Figure G-25) is oriented south to north and extends along the eastern edge of the total uranium plume. The southern half of the cross section illustrates the effect that recharge is having on the migration of the plume. The top of the 20 μg/L total uranium plume is located approximately 30 to 40 feet below the top of the water table. The uranium plume appears to begin to migrate deeper into the aquifer just south of Geoprobe™ location 12232.

Cross section C-C' (Figure G-26) is oriented north to south and extends through some of the thickest portions of the total uranium plume. Beneath Geoprobe™ locations 12230 and 12194, the 20 μg/L total uranium plume is approximately 60 to 70 feet thick. The leading edge of the plume is also thick.

Cross section D-D' (Figure G-27) is oriented west to east and extends along Willey road, just north of cross section A-A'. Similar to cross section A-A', this section offers another view of the plume along a vertical section that is slightly north of Cross Section A-A'.

Cross section E-E' (Figure G-28) is oriented northwest to southeast and extends along Willey Road, in the northwest, then deviates southeast from Willey Road. The cross section illustrates how the total uranium plume appears to be migrating deeper in the aquifer in the southeast then it is in the northwest. The top of the 20 μg/L total uranium plume is at the water table in the northwest, but is located approximately 10 to 15 feet below the water table in the southeast.

Cross section F-F' (Figure G-29) is oriented north to south, and extends from the Storm Sewer Outfall Ditch south to the South Plume Extraction Module Well 3. The cross section illustrates how the total uranium plume appears to be migrating deeper in the aquifer as it moves to the south toward the recovery wells in the South Plume Module. The total uranium plume also becomes much thinner as it moves to the South.

Cross Section G-G' (Figure G-30) is oriented north to south. The cross section depicts the vertical profile of the total uranium plume north of the South Plume Extraction Wells but south of Willey Road.

Cross Section H-H' (Figure G-31) is oriented west to east. The cross section depicts the vertical profile of the total uranium plume north of the South Plume Extraction Wells but south of Willey Road.

A Kriged version of the updated total uranium plume map was also produced. Figures G-32, G-33 and G-34 depict the Kriged Plume for model layers 1, 2, and 3, respectively. The updated total uranium plume data set (as described earlier) was Kriged with five foot depth intervals from the top of the water table to the bottom of model layer three (the top of the clay interbed). The five foot Kriged layers were grouped by depth corresponding to the SWIFT model layers one, two or three.

Each group of Kriged layers was examined for the maximum concentration found in that group corresponding to SWIFT model layers one, two, or three and that maximum Kriged concentration was assigned to the entire SWIFT model layer for that model block. This was done in order to ensure that the plume resulting from the Kriging process was still a conservative approximation to the actual groundwater plume.

The resulting total uranium plume was used as initial conditions in the final baseline scenario modeling presented in Section 5.0.

G.6.0 SUMMARY OF RESULTS

- The plume is primarily in the top 40 feet of the saturated zone.
- The location-specific maximum uranium concentrations are detected within 20 feet of the groundwater table in most areas.
- Maximum uranium concentrations are detected about 20 feet below the groundwater table at eleven locations.
- At eight locations (i.e., 31565, 31564, 31561, 12192, 12193, 12228, 12237 and 12241) the detected maximum uranium concentration is more than 20 feet below groundwater table. Five of the eight locations are close to areas of higher vertical infiltration (e.g., near Paddys Run, SSOD and on edge of till). The only off-property location away from Paddys Run where the maximum uranium concentration is greater than 20 feet below the groundwater table (i.e., at 30 feet in 12228) may be due to pumping of a nearby home owner's well.
- The 20 μg/L plume reaches the typical Type 3 well screen elevation (i.e, about 450 feet amsl) in four on-property locations (i.e., 12230, 12194, 12193, and 3069) along the southern branch of the SSOD and three (3) off-property locations (i.e, 3125, South Plume recovery well #1 and #2) around the western portion of the South Plume recovery well field.
- The screen intervals of South Plume recovery well #3 and #4 are the same elevation as the uranium plume in the eastern portion of the South Plume.
- In most areas further away from the sources of the plume (i.e., the SSOD and Paddys Run), the plume becomes thinner with maximum concentrations found below the groundwater table, so that some existing Type 2 monitoring wells can potentially miss the plume (e.g., 2880 and 2881).
- The current interpretation of the off-property uranium plume extent is considerably larger than the DMEPP plume as shown in Figures G-2 and G-3 due to the incorporation of the new Geoprobe data.

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G.7.0 Recommendations

The Geoprobe™ sampling tool has proved to be very useful for obtaining groundwater samples without the installation of a permanent monitoring well. This technique may be used throughout the aquifer restoration to collect data on the progress of the remedy and to aid in determining the optimal location and depth of any additional monitoring wells which may be installed in the future.

TABLE G-1

GEOPROBE™ RESULTS
LOCATION 12192

Easting '27 = 1380723.5
Northing '27 = 476488.8
Reference Elevation = 575.0 feet amsl
Depth to Water Table = 55.0 feet
Work Duration = October 23-30, 1996

Sample Point	Elevation (ft amsl)	Depth Below Surface (ft)	Depth Below Water Table (@ 520.0 feet amsl)	Total Uranium Conc. (μg/L)
1	519	56	1	3.0
2	509	66	10	1.1
3	499	76	20	1.0
4	489	86	30	20
5	479	96	40	203
6	469	106	50	331
7	459	116	60	70
8	449	126	70	14
9	439	136	80	9.3
10	429	146	90	2.3
11	419	156	100	1.2

TABLE G-2

GEOPROBE™ RESULTS
LOCATION 12193

Easting '27 = 1380873.3
Northing '27 = 476147.6
Reference Elevation = 577.0 feet amsl
Depth to Water Table = 57.0 feet
Work Duration = October 30 - November 7, 1996

Sample Point	Elevation (ft amsl)	Depth Below Surface (ft)	Depth Below Water Table (@ 520.0 feet amsl)	Total Uranium Conc. (μg/L)
1	517	60	1	2.0
2	507	70	10	1.1
3	500	77	20	0.9
4	490	87	30	1.8
5	480	97	40	34.0
6	470	107	50	5.3
7	460	117	60	2.6
8	450	127	70	5.2
9	440	137	80	1.2
10	430	147	90	1.0
11	420	157	100	00.2

TABLE G-3

GEOPROBE™ RESULTS
LOCATION 12197

Easting '27 = 1380923.6
Northing '27 = 476029.1
Reference Elevation = 568.4 feet amsl
Depth to Water Table = 47.7 feet
Work Duration = December 23-28, 1996

Sample Point	Elevation (ft amsl)	Depth Below Surface (ft)	Depth Below Water Table (@ 520.7 amsl)	Total Uranium Conc. (μg/L)
1	519.7	48.7	1	1.0
2	510.7	57.7	10	0.7
3	500.7	67.7	20	0.5
4	490.7	77.7	30	0.4
5	480.7	87.7	40	0.4
6	470.7	97.7	50	0.2
7	460.7	107.7	60	0.4
8	450.7	117.7	70	0.3
9	440.7	127.7	80	0.4
10	430.7	137.7	90	0.4
11	420.7	147.7	100	0.5

TABLE G-4

GEOPROBE™ RESULTS
LOCATION 12194

Easting '27 = 1380426.1
Northing '27 = 476264.1
Reference Elevation = 565.2 feet amsl
Depth to Water Table = 45.2 feet
Work Duration = November 12-20, 1996

Sample Point	Elevation (ft amsl)	Depth Below Surface (ft)	Depth Below Water Table (@ 520.0 feet amsl)	Total Uranium Conc. (μg/L)
1	519.0	46.2	1	0.7
2	510.0	55.2	10	295
3	500.0	65.2	20	497
4	490.0	75.2	30	341
5	480.0	85.2	40	199
6	470.0	95.2	50	106
7	460.0	105.2	60	9.0
8	450.0	115.2	70	19
9	440.0	125.2	80	4.8
10	430.0	135.2	90	2.0
11	420.0	145.2	100	0.7

TABLE G-5

GEOPROBE™ RESULTS
LOCATION 12195

Easting '27 = 1380507.0
Northing '27 = 476108.8
Reference Elevation = 568.3 feet amsl
Depth to Water Table = 48.3 feet
Work Duration = November 26 - December 9, 1996

Sample Point	Elevation* (ft amsl)	Depth Below Surface* (ft)	Depth Below Water Table* (@ 520.0 feet amsl)	Total Uranium Conc. (μg/L)
1	517.9	50.4	1	0.8
2	508.9	59.4	10	120
3	499.8	68.5	20	300
4	490.7	77.6	30	11
5	481.7	86.6	40	72
6	472.6	95.7	50	29
7	463.6	104.7	60	5.0
8	454.5	113.8	70	1.6

*Note that the Elevations have been corrected for a bent rod.

TABLE G-6

GEOPROBE™ RESULTS
LOCATION 12196

Easting '27 = 1380642.6
Northing '27 = 475861.3
Reference Elevation = 582.5 feet amsl
Depth to Water Table = 63.2 feet
Work Duration = December 10-20, 1996

Sample Point	Elevation (ft amsl)	Depth Below Surface (ft)	Depth Below Water Table (@ 519.5 feet amsl)	Total Uranium Conc. (μg/L)
1	518.3	64.2	1	0.5
2	509.3	73.2	10	0.3
3	599.3	83.2	20	0.7
4	489.3	93.2	30	0.5
5	479.3	103.2	40	0.3
6	469.3	113.2	50	0.5
7	459.3	123.2	60	0.7
8	449.3	133.2	70	0.4
9	439.3	143.2	80	1.6

TABLE G-7

GEOPROBE™ RESULTS
LOCATION 12230

Easting '27 = 1380098.8
Northing '27 = 476728.5
Reference Elevation = 570.0 feet amsl
Depth to Water Table = 49.0 feet
Work Duration = February 7-13, 1997

Sample Point	Elevation (ft amsl)	Depth Below Surface (ft)	Depth Below Water Table (@ 520.0 feet amsl)	Total Uranium Conc. (μg/L)
1	520	50	1	168
2	511	59	10	258
3	501	69	20	193
4	491	79	30	245
5	481	89	40	125
6	471	99	50	69
7	461	109	60	59
8	451	119	70	13
9	441	129	80	6.0
10	431	139	90	3.0

TABLE G-8

GEOPROBE™ RESULTS
LOCATION 12231

Easting '27 = 1380264.8
Northing '27 = 476524.9
Reference Elevation = 562.97 feet amsl
Depth to Water Table = 42.0 feet
Work Duration = January 31 - February 6, 1997

Sample Point	Elevation (ft amsl)	Depth Below Surface (ft)	Depth Below Water Table (@ 520.97 feet amsl)	Total Uranium Conc. (μg/L)
1	519.5	43.5	1.5	240
2	511	52	10	387
3	501	62	20	397
4	491	72	30	287
5	481	82	40	177
6	471	92	50	113
7	460.5	102.5	60.5	8.0
8	451	112	70	7.4
9	441	122	80	5.0
10	431	132	90	1.0

TABLE G-9

GEOPROBE™ RESULTS
LOCATION 12232

Easting '27 = 1380613.9
Northing '27 = 476769.9
Reference Elevation = 574.59 feet amsl
Depth to Water Table = 54.0 feet
Work Duration = January 7-11, 1997

Sample Point	Elevation (ft amsl)	Depth Below Surface (ft)	Depth Below Water Table (@ 520.0 feet amsl)	Total Uranium Conc. (μg/L)
1	520	55	1	44
2	511	64	10	160
3	501	74	20	325
4	491	84	30	76
5	481	94	40	15
6	471	104	50	3.4
7	461	114	60	3.2
8	451	124	70	3.0

TABLE G-10

GEOPROBE™ RESULTS
LOCATION 12228

Easting '83 = 1380136.5
Northing '83 = 475705.1
Reference Elevation = 575.6 feet amsl
Depth to Water Table = 55.5 feet
Work Duration = December 31, 1996 - January 4, 1997

Sample Point	Elevation (ft amsl)	Depth Below Surface (ft)	Depth Below Water Table (@ 520.1 amsl)	Total Uranium Conc. (μg/L)
1	519.1	56.5	1	6.6
2	510.1	65.5	10	6.5
3	500.1	75.5	20	67
4	490.1	85.5	30	96
5	480.1	95.5	40	28
6	470.1	105.5	50	4.8
7	460.1	115.5	60	5.5
8	450.1	125.5	70	1.5
9	440.1	135.5	80	0.5
10	430.1	145.5	90	0.5

* Note that coordinates are '83 coordinates

TABLE G-11

GEOPROBE™ RESULTS
LOCATION 12233

Easting '27 = 1380355.7
Northing '27 = 475449.6
Reference Elevation = 579.55 feet amsl
Depth to Water Table = 59.4 feet
Work Duration = January 14-23, 1997

Sample Point	Elevation (ft amsl)	Depth Below Surface (ft)	Depth Below Water Table (@ 520.0 feet amsl)	Total Uranium Conc. (μg/L)
1	520	60	1	0.5
2	511	69	10	3.4
3	501	79	20	123
4	491	89	30	83
5	481	99	40	27
6	471	109	50	3.1
7	461	119	60	1.0
8	451	129	70	2.2

TABLE G-12

GEOPROBE™ RESULTS
LOCATION 12234

Easting '27 = 1380563.5
Northing '27 = 475238.8
Reference Elevation = 580.58 feet amsl
Depth to Water Table = 60.8 feet
Work Duration = February 14-20, 1997

Sample Point	Elevation (ft amsl)	Depth Below Surface (ft)	Depth Below Water Table (@ 520.0 feet amsl)	Total Uranium Conc. (μg/L)
1	519	62	1	0.6
2	510	71	10	1.7
3	500	81	20	53
4	490	91	30	2.4
5	480	101	40	2.5
6	470	111	50	2.0
7	460	121	60	1.4
8	450	131	70	0.4

TABLE G-13

GEOPROBE™ RESULTS
LOCATION 12235

Easting '27 = 1380253.5
Northing '27 = 475034.6
Reference Elevation = 581.11 feet amsl
Depth to Water Table = 61.8 feet
Work Duration = February 22-27, 1997

Sample Point	Elevation (ft amsl)	Depth Below Surface (ft)	Depth Below Water Table (@ 520.0 feet amsl)	Total Uranium Conc. (μg/L)
1	518	63	1	0.8
2	509	72	10	6.3
3	499	82	20	127
4	489	92	30	36
5	479	102	40	3.2
6	469	112	50	2.0
7	459	122	60	1.2
8	449	132	70	0.3

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TABLE G-14

GEOPROBE™ RESULTS
LOCATION 12229

Easting '27 = 1380065.1
Northing '27 = 476120.9
Reference Elevation = 577.7 feet amsl
Depth to Water Table = 57.0 feet
Work Duration = January 25-31, 1997

Sample Point	Elevation (ft amsl)	Depth Below Surface (ft)	Depth Below Water Table (@ 520.0 feet amsl)	Total Uranium Conc. (μg/L)
1	520	58	1	86
2	511	67	10	99
3	501	77	20	64
4	491	87	30	40
5	481	97	40	21
6	471	107	50	1.6
7	461	117	60	1.3
8	451	127	70	1.3

TABLE G-15

GEOPROBE™ RESULTS
LOCATION 12236

Easting '27 = 1379443.1
Northing '27 = 475741.1
Reference Elevation = 535.0 feet amsl
Depth to Water Table = 12.8 feet
Work Duration = March 19-22, 1997

Sample Point	Elevation (ft amsl)	Depth Below Surface (ft)	Depth Below Water Table (@ 520.0 feet amsl)	Total Uranium Conc. (μg/L)
1	521	14	1	8.1
2	512	23	10	61
3	502	33	20	70
4	492	43	30	46
5	482	53	40	26
6	472	63	50	41
7	462	73	60	3.3
8	452	83	70	1.1
9	442	93	80	0.8
10	432	103	90	0.4
11	422	113	100	0.7

000309

TABLE G-16

GEOPROBE™ RESULTS
LOCATION 12237

Easting '27 = 1379483.6
Northing '27 = 475256.3
Reference Elevation = 533.44 feet amsl
Depth to Water Table = 12.3 feet
Work Duration = March 10, 16-18, 1997

Sample Point	Elevation (ft amsl)	Depth Below Surface (ft)	Depth Below Water Table (@ 520.0 feet amsl)	Total Uranium Conc. (μg/L)
1	520	13	1	16
2	511	22	10	91
3	501	32	20	99
4	491	42	30	102
5	481	52	40	73
6	471	62	50	49
7	461	72	60	16
8	451	82	70	2.0
9	441	92	80	1.1

TABLE G-17

GEOPROBE™ RESULTS
LOCATION 12238

Easting '27 = 1379826.4
Northing '27 = 475467.7
Reference Elevation = 575.12 feet amsl
Depth to Water Table = 55.1 feet
Work Duration = March 22-26, 1997

Sample Point	Elevation (ft amsl)	Depth Below Surface (ft)	Depth Below Water Table (@ 520.0 feet amsl)	Total Uranium Conc. (μg/L)
1	519	56	1	69
2	510	65	10	97
3	500	75	20	31
4	490	85	30	46
5	480	95	40	94
6	470	105	50	11
7	460	115	60	13
8	450	5	70	4.7
9	440	135	80	2.7

000311

TABLE G-18

GEOPROBE™ RESULTS
LOCATION 12241

Easting '27 = 1379564.7
Northing '27 = 476113.9
Reference Elevation = 538.87 feet amsl
Depth to Water Table = 16.0 feet
Work Duration = March 5-7, 1997

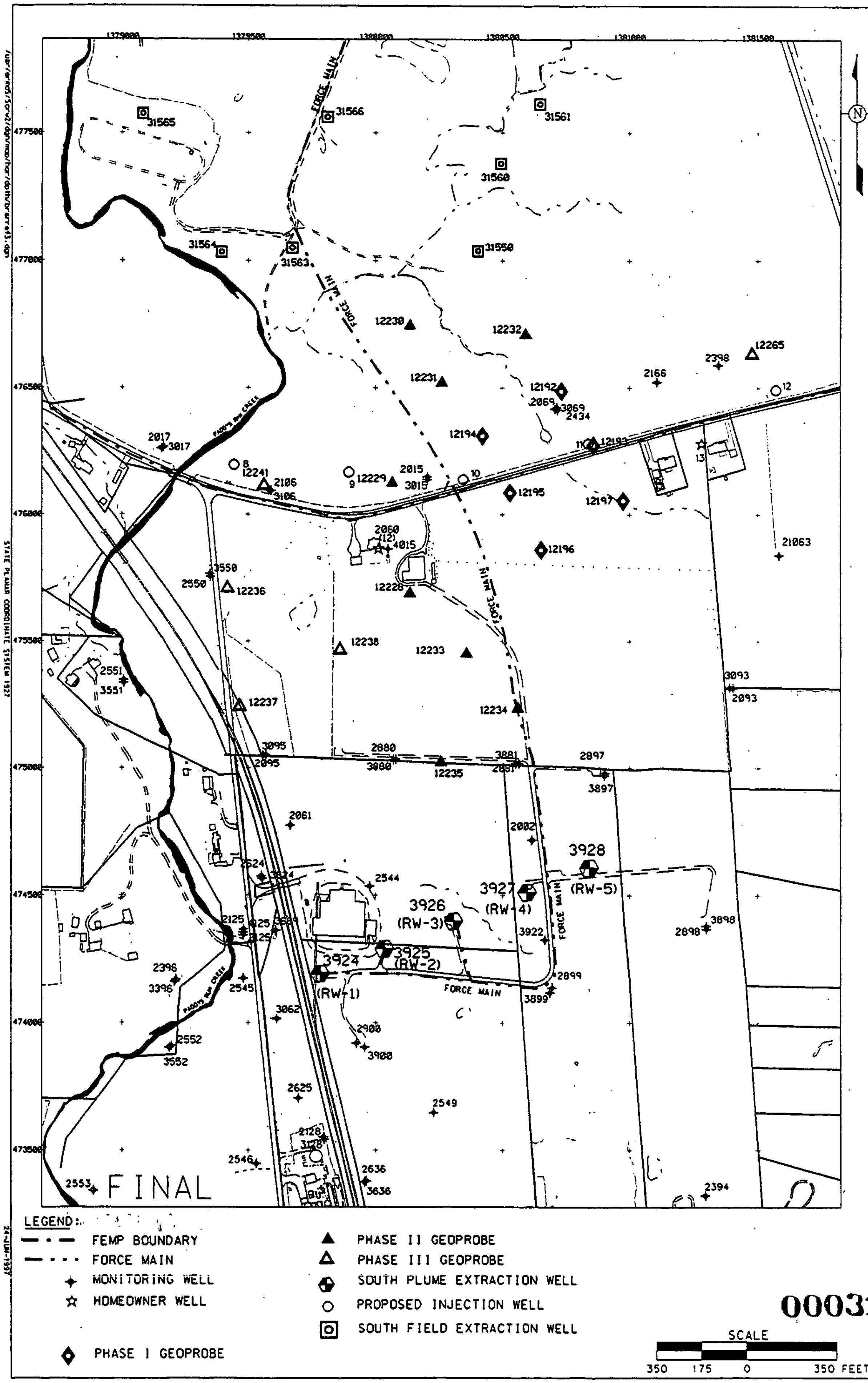
Sample Point	Elevation (ft amsl)	Depth Below Surface (ft)	Depth Below Water Table (@ 520.0 feet amsl)	Total Uranium Conc. (μg/L)
1	522	17	1	4.7
2	513	26	10	41
3	503	36	20	45
4	493	46	30	72
5	483	56	40	18
6	473	66	50	6.8
7	463	76	60	1.2
8	453	86	70	1.0
9	443	96	80	1.3
10	433	106	90	2.3

TABLE G-19

GEOPROBE™ RESULTS
LOCATION 12265

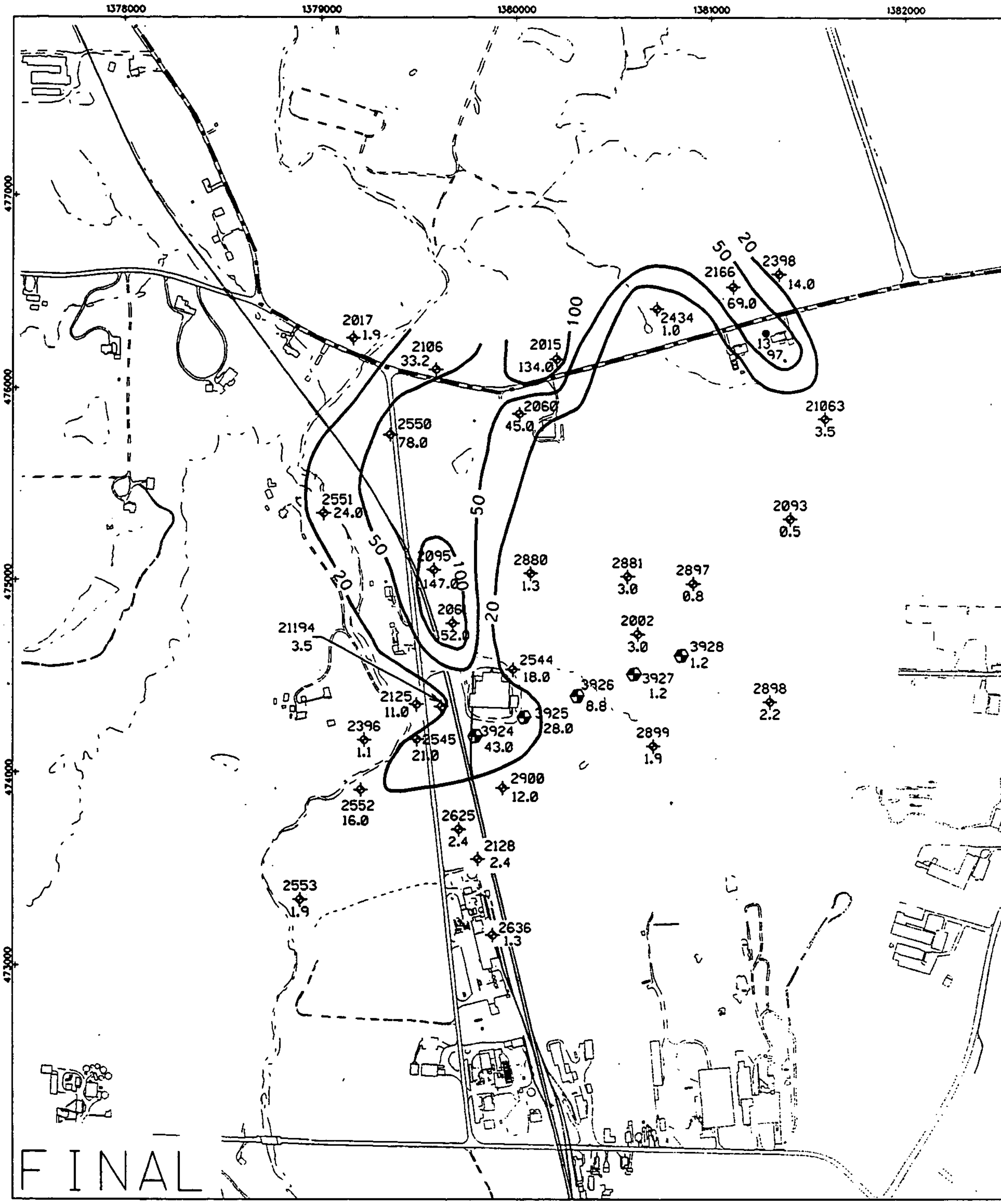
Easting '27 = 1349977.2
Northing '27 = 4766619.4
Reference Elevation = 577.95 feet amsl
Depth to Water Table = 57.7 feet
Work Duration = May 14-20, 1997

Sample Point	Elevation (ft amsl)	Depth Below Surface (ft)	Depth Below Water Table (@ 520.0 feet amsl)	Total Uranium Conc. (μg/L)
1	519	59	1	0.8
2	511	67	10	2.2
3	501	77	20	0.5
4	491	87	30	0.6
5	481	97	40	2.7
6	471	107	50	1.9
7	461	117	60	1.7
8	451	127	70	1.1
9	441	137	80	0.5



000314

FIGURE G-1. GEOPROBE LOCATION MAP



/USR/ERMA5/SCRW2/DGN/MAP/HOR/DPTH/BRSR080.DGN FER OU5 8/20/96 STATE PLANAR COORDINATE SYSTEM 1927

NOTE: BASED ON SECOND QUARTER 1996 DATA

LEGEND:

— · — · — FEMP BOUNDARY

20 TOTAL URANIUM CONCENTRATION CONTOUR

2553 1.1 WELL NUMBER TOTAL URANIUM CONCENTRATION ($\mu g/L$)

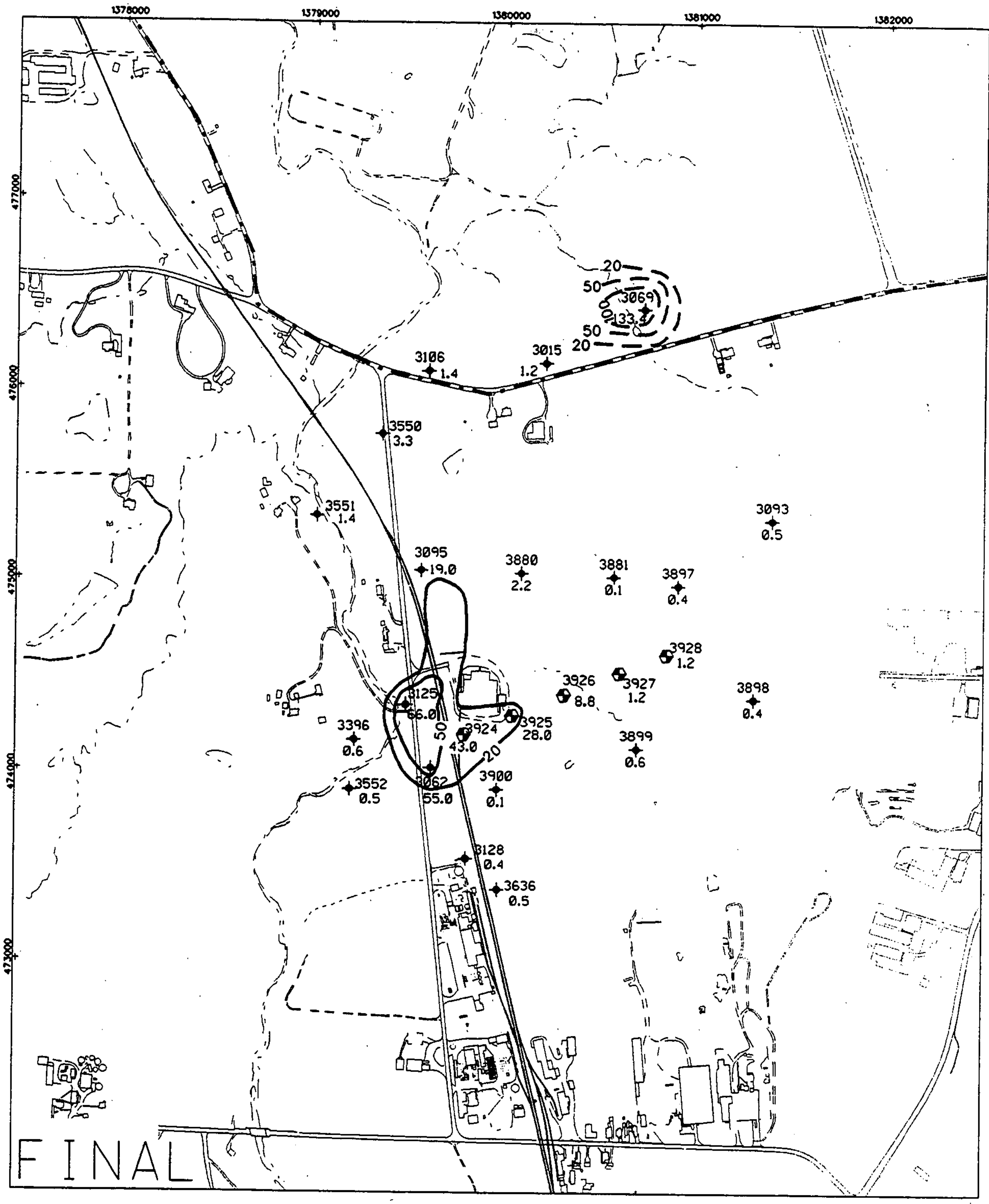
000315

SCALE

800 400 0 800 FEET

FIGURE G-2. DMEPP TYPE 2 TOTAL URANIUM PLUME MAP

/USR/ERMA5/5CRW2/DGN/MAP/HOR/DPTH/BRSR081.DGN FER OU5 4/9/97 STATE PLANAR COORDINATE SYSTEM 1927



LEGEND:

FEMP BOUNDARY

20 TOTAL URANIUM CONCENTRATION CONTOUR

3553 1.1 WELL NUMBER TOTAL URANIUM CONCENTRATION (μg/L)

NOTE: BASED ON SECOND QUARTER 1996 DATA
DASHED CONTOURS BASED ON ONE DATA POINT

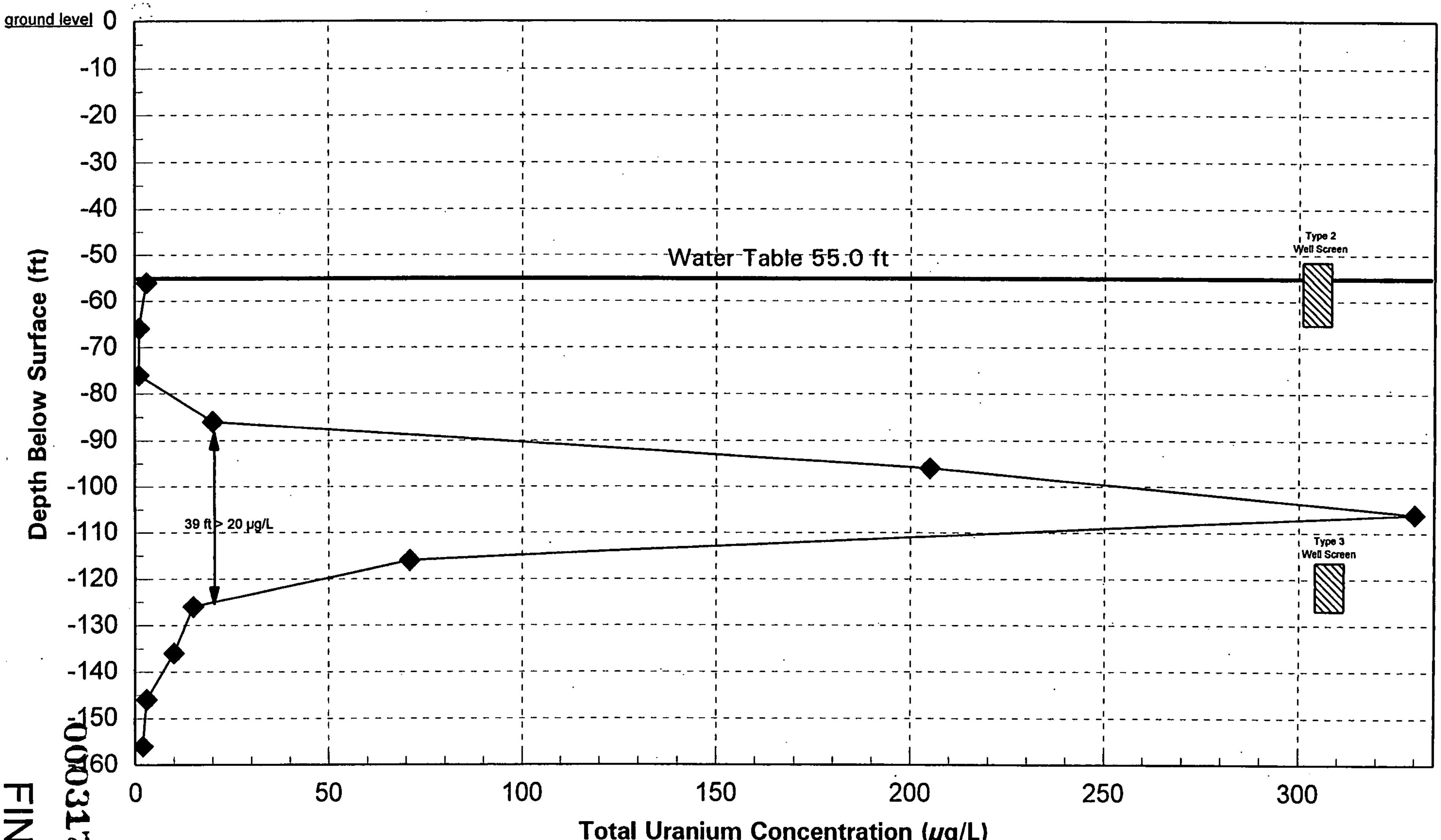
000316

SCALE

800 400 0 800 FEET

FIGURE G-3. DMEPP TYPE 3 TOTAL URANIUM PLUME MAP

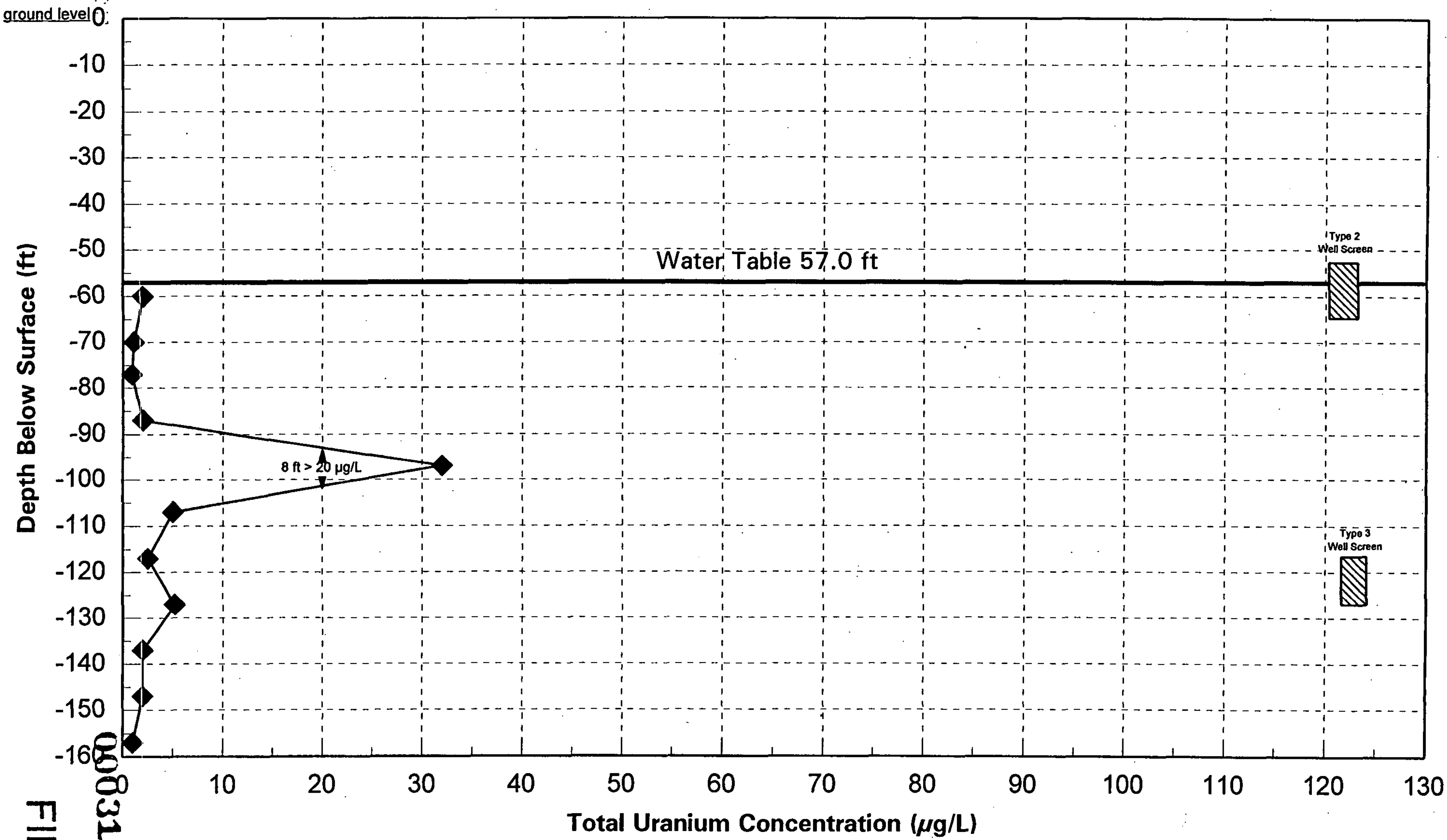
FIGURE G-4
GEOPROBE™ RESULTS FOR LOCATION 12192
TOTAL URANIUM CONCENTRATION (μg/L) VERSUS DEPTH BELOW SURFACE (ft)



000317

FINAL

FIGURE G-5
GEOPROBE™ RESULTS FOR LOCATION 12193
TOTAL URANIUM CONCENTRATION (µg/L) VERSUS DEPTH BELOW SURFACE (ft)

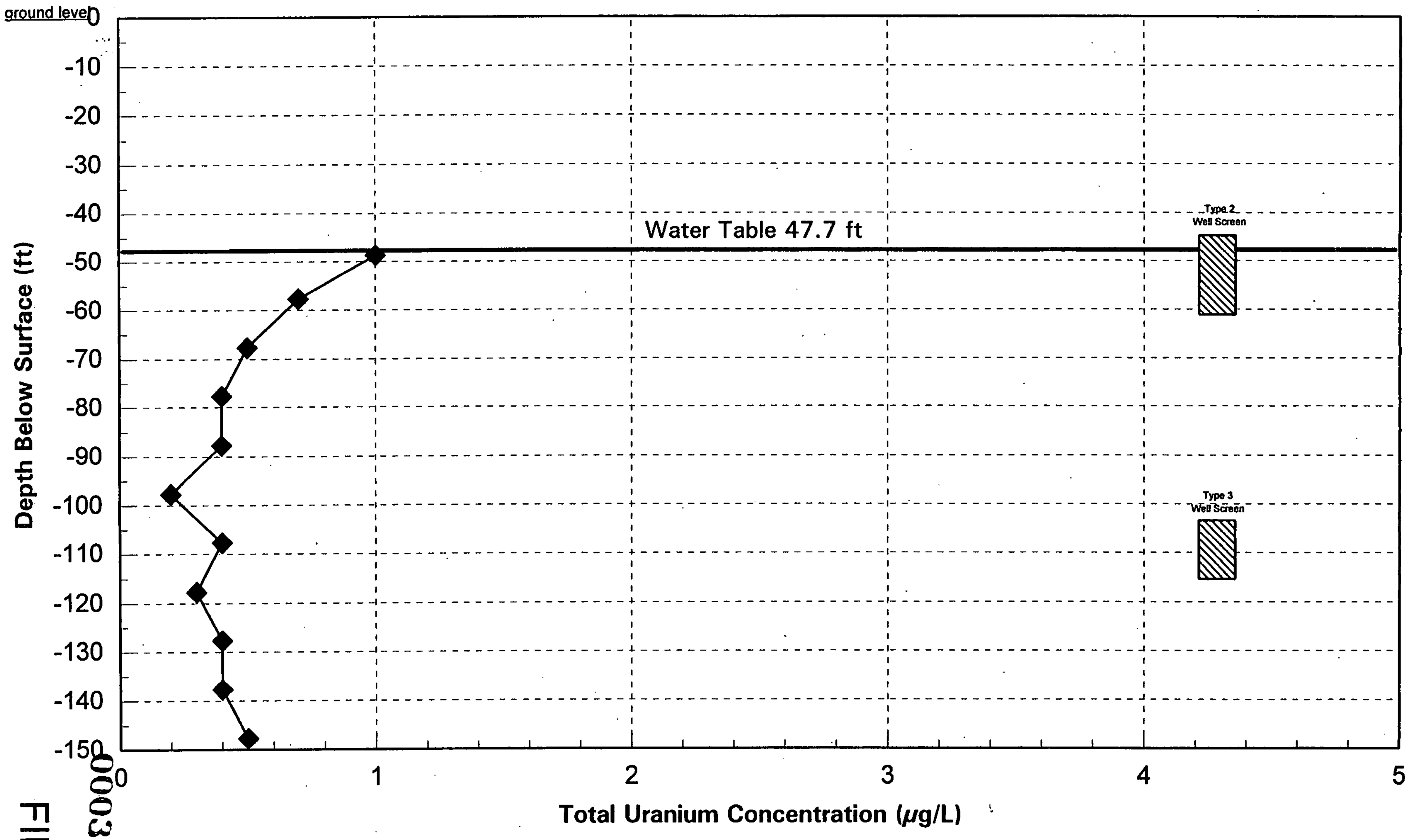


000318

FINAL

8651

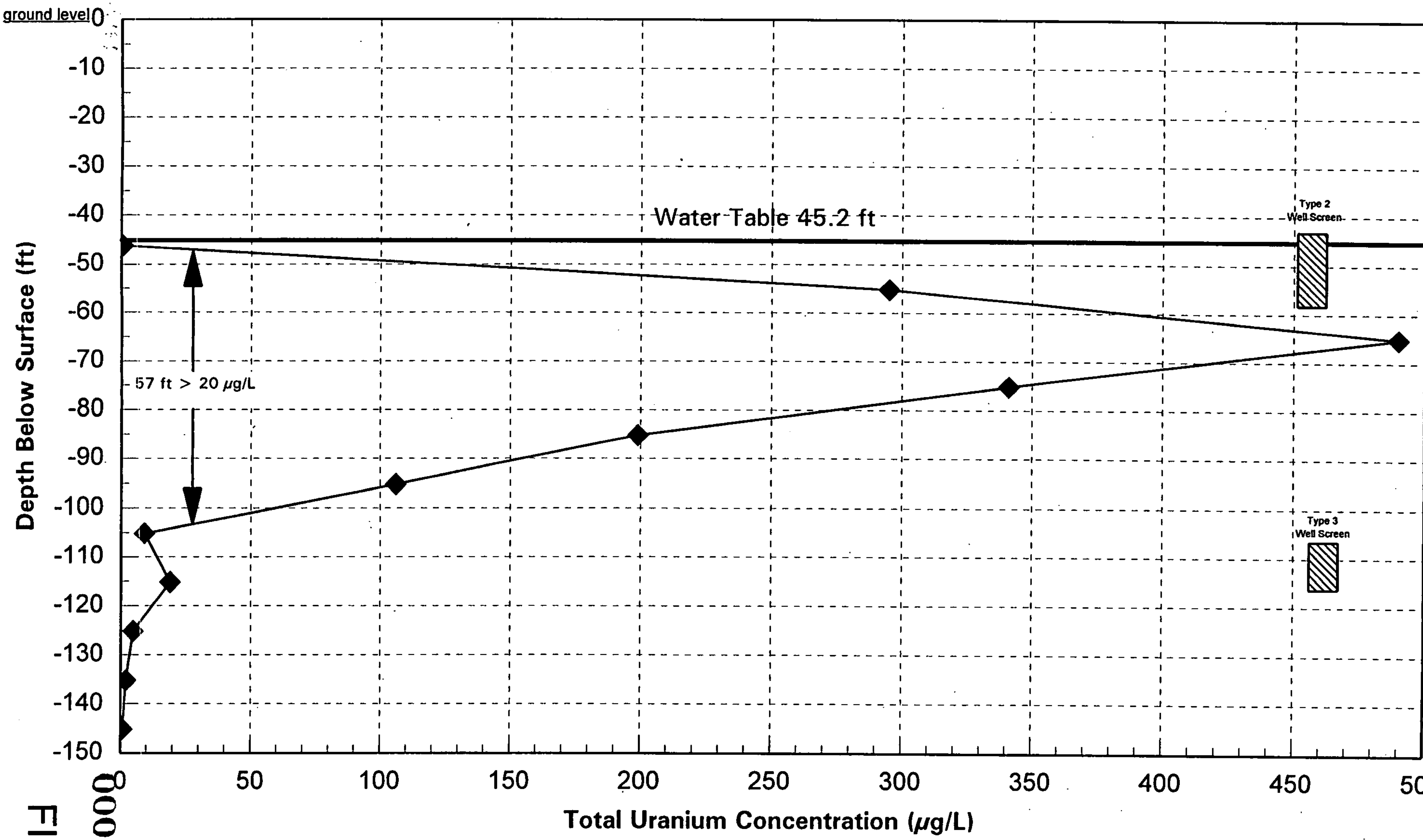
FIGURE G-6
GEOPROBE™ RESULTS FOR LOCATION 12197
TOTAL URANIUM CONCENTRATION (µg/L) VERSUS DEPTH BELOW SURFACE (ft)



000319

FINAL

FIGURE G-7
GEOPROBE™ RESULTS FOR LOCATION 12194
TOTAL URANIUM CONCENTRATION (µg/L) VERSUS DEPTH BELOW SURFACE (ft)



000320

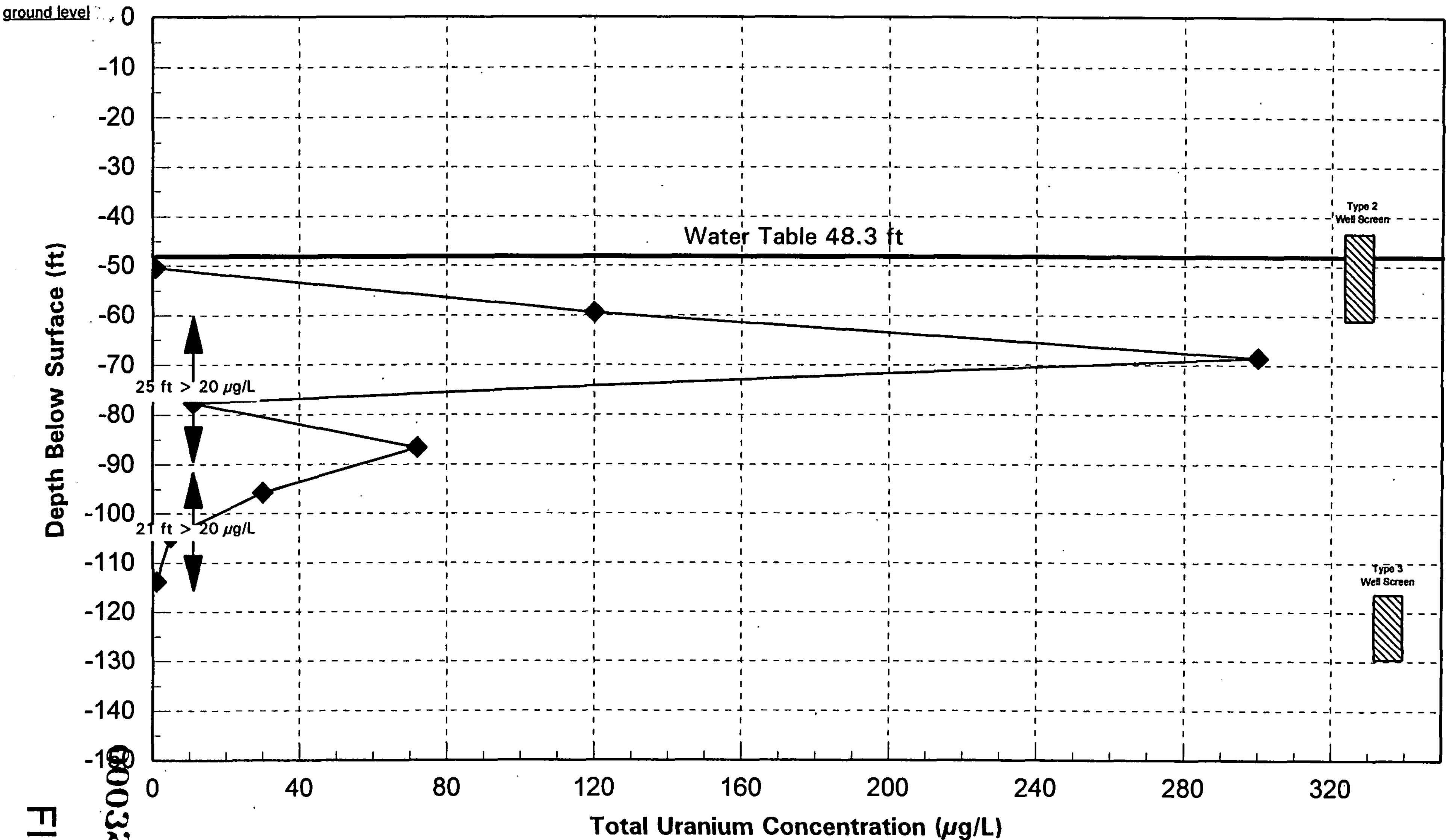
FINAL

851

FIGURE G-8

GEOPROBE™ RESULTS FOR LOCATION 12195

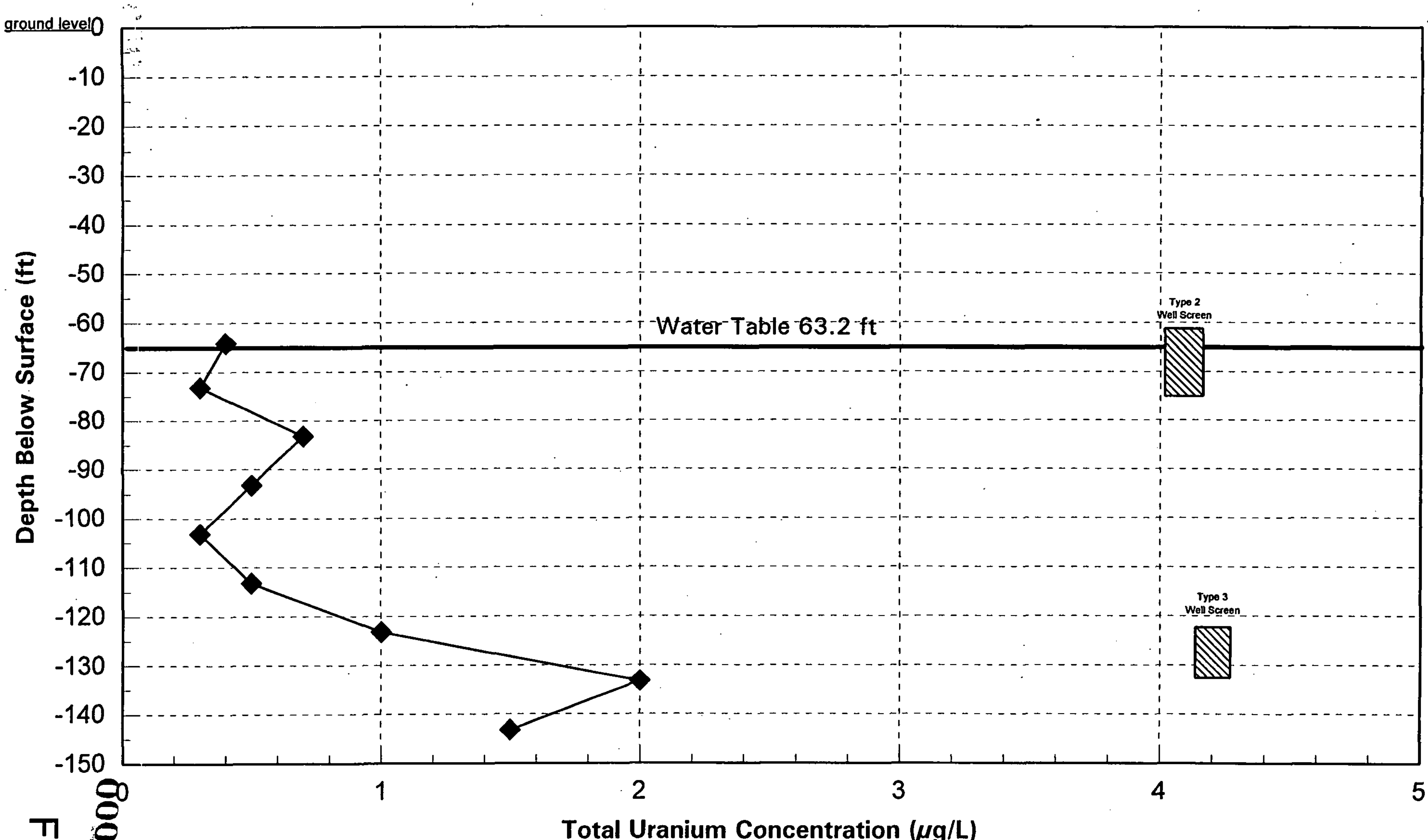
TOTAL URANIUM CONCENTRATION (µg/L) VERSUS DEPTH BELOW SURFACE (ft)



000321

FINAL

FIGURE G-9
GEOPROBE™ RESULTS FOR LOCATION 12196
TOTAL URANIUM CONCENTRATION (µg/L) VERSUS DEPTH BELOW SURFACE (ft)

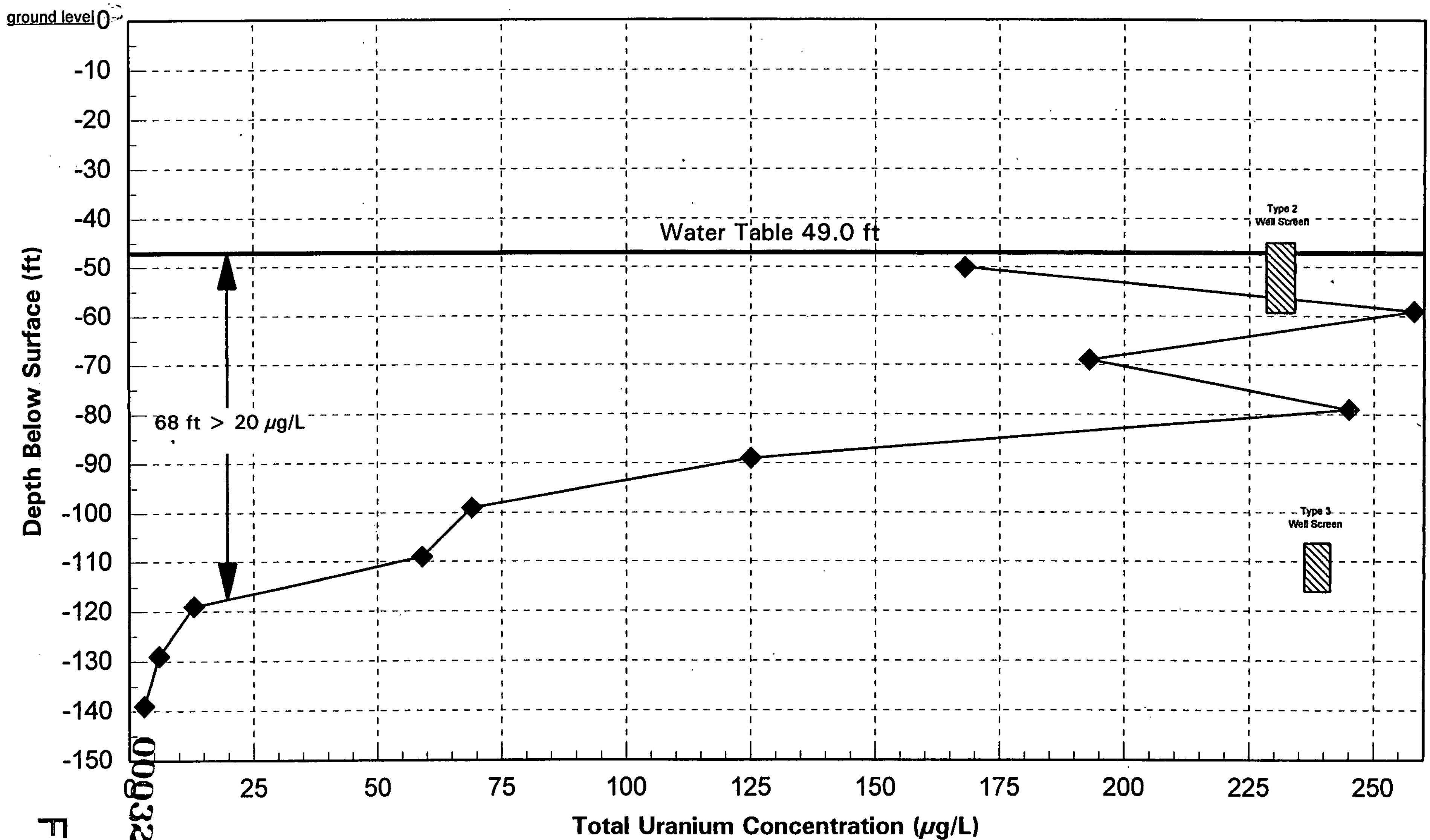


FINAL

000322

8651

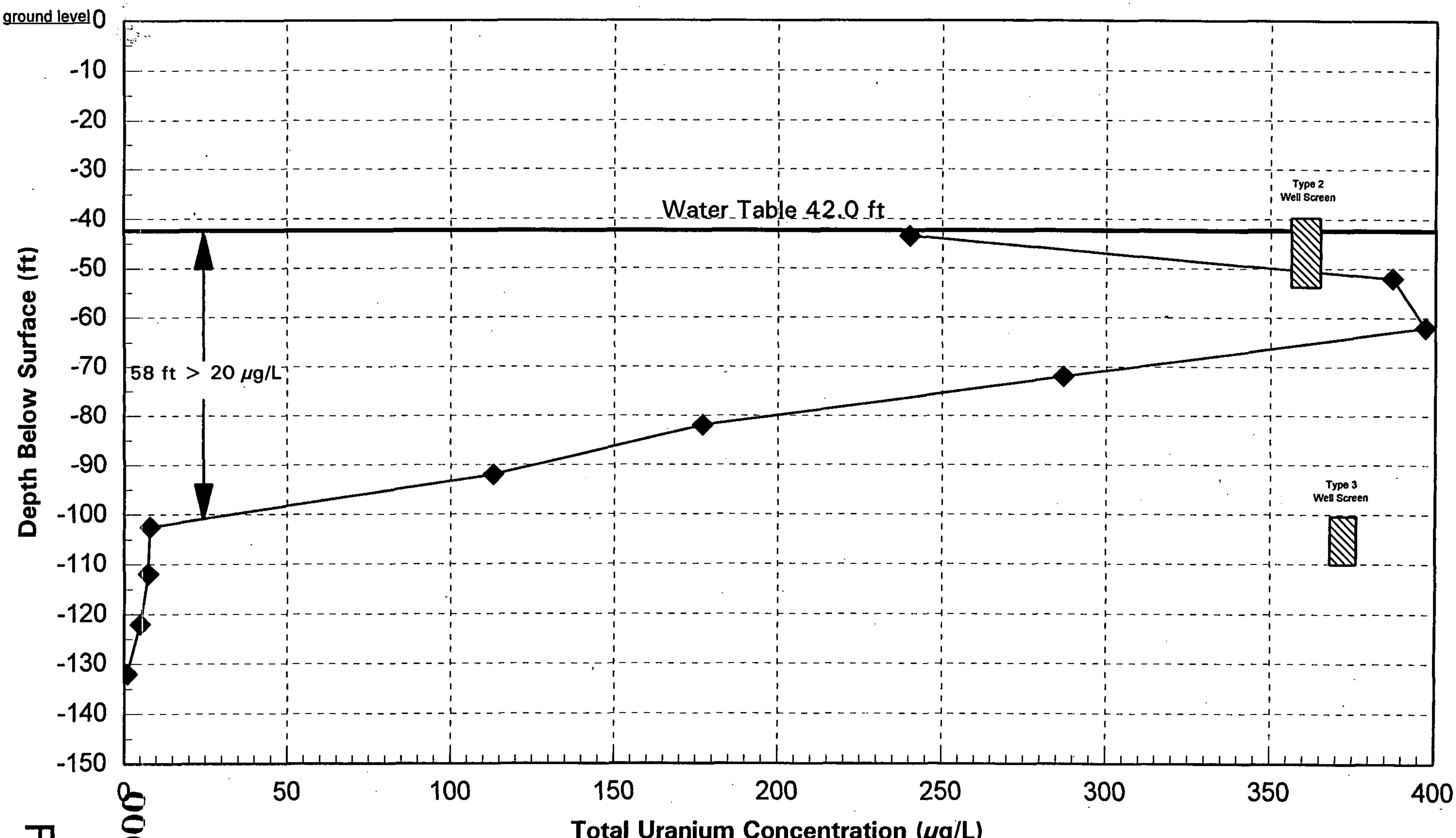
FIGURE G-10
GEOPROBE™ RESULTS FOR LOCATION 12230
TOTAL URANIUM CONCENTRATION (µg/L) VERSUS DEPTH BELOW SURFACE (ft)



000323

FINAL

FIGURE G-11
GEOPROBE™ RESULTS FOR LOCATION 12231
TOTAL URANIUM CONCENTRATION (µg/L) VERSUS DEPTH BELOW SURFACE (ft)

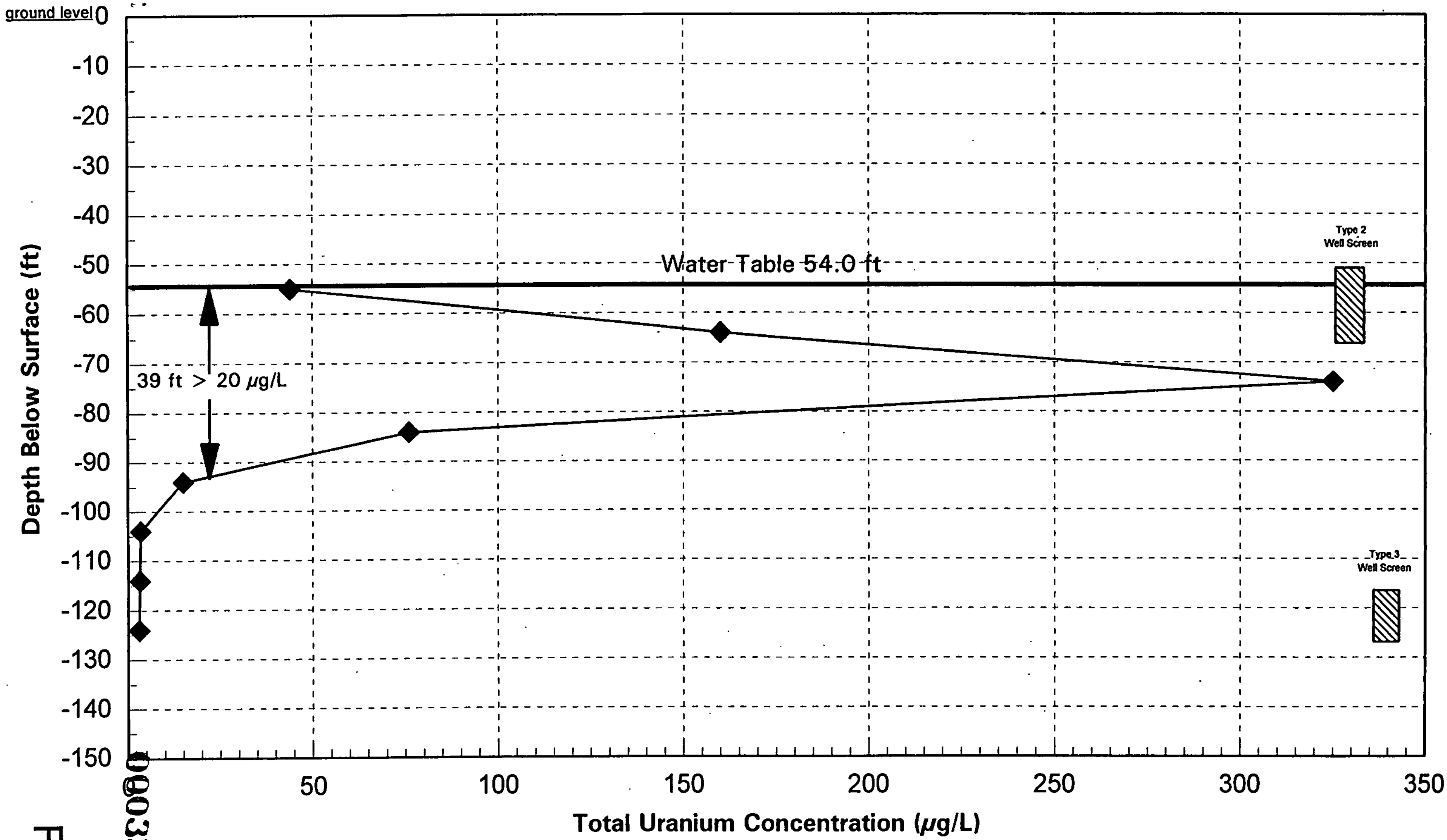


000324

FINAL

851

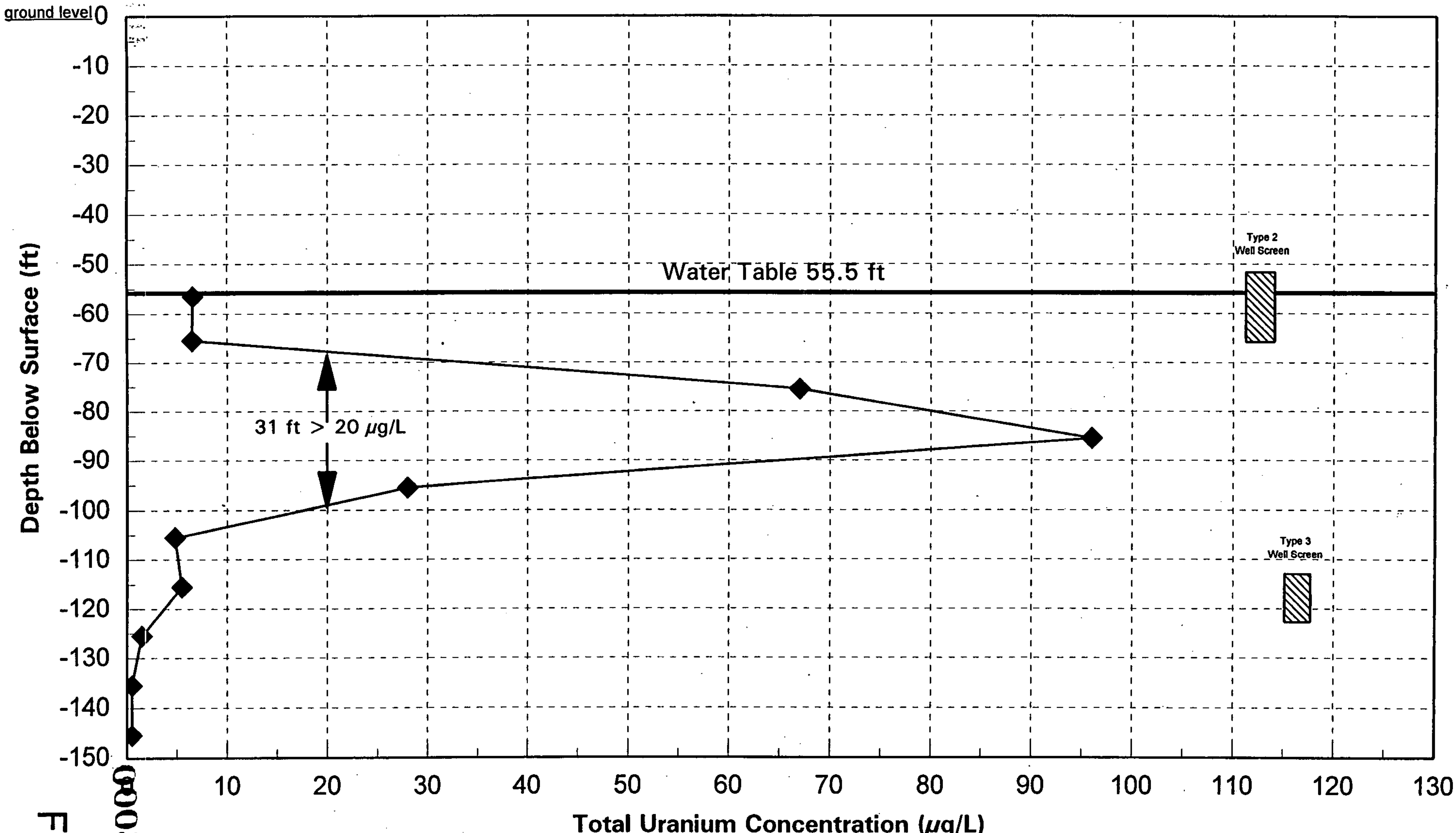
FIGURE G-12
GEOPROBE™ RESULTS FOR LOCATION 12232
TOTAL URANIUM CONCENTRATION (µg/L) VERSUS DEPTH BELOW SURFACE (ft)



000325

FINAL

FIGURE G-13
GEOPROBE™ RESULTS FOR LOCATION 12228
TOTAL URANIUM CONCENTRATION (µg/L) VERSUS DEPTH BELOW SURFACE (ft)

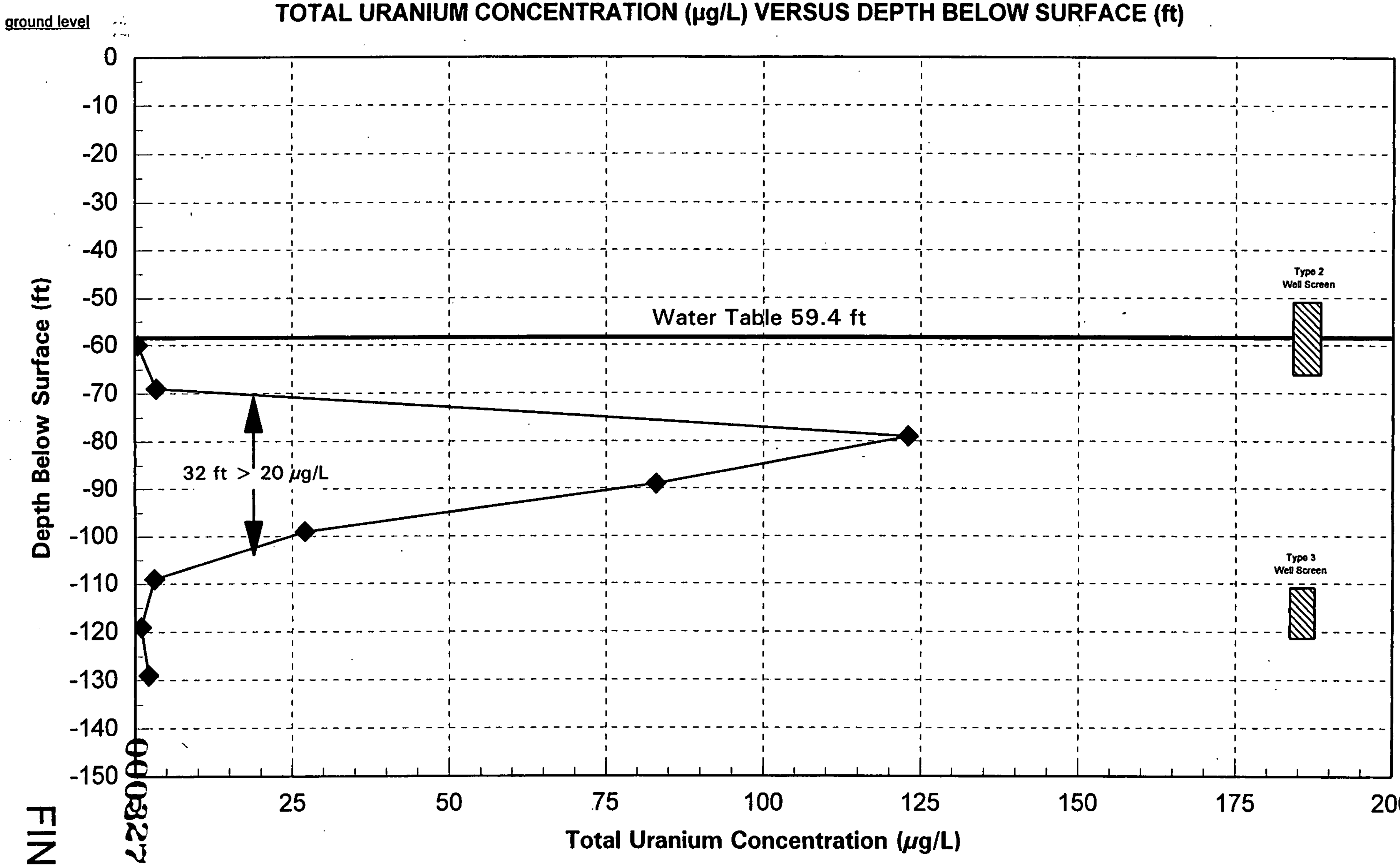


000326

FINAL

8651

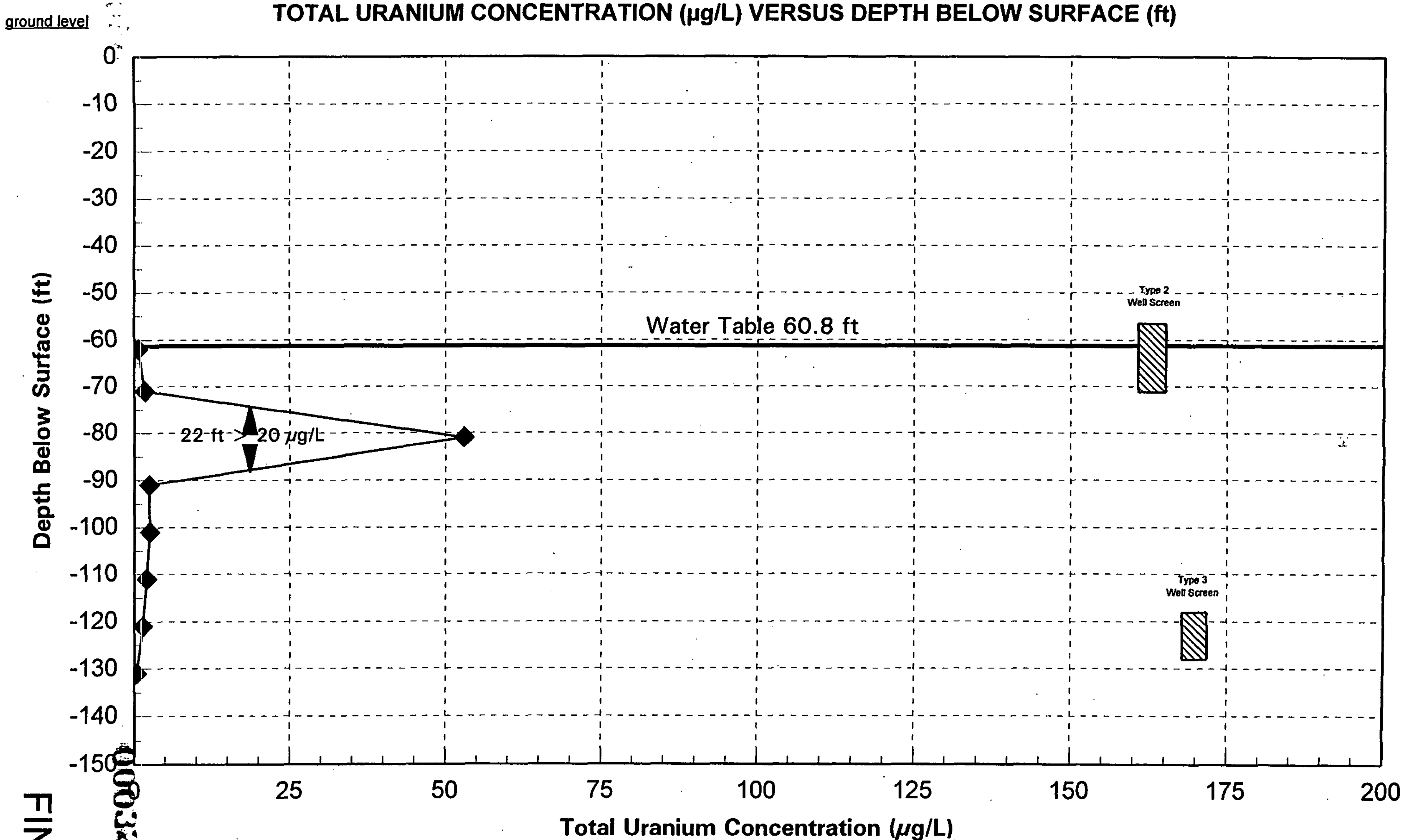
FIGURE G-14
GEOPROBE™ RESULTS FOR LOCATION 12233
TOTAL URANIUM CONCENTRATION (µg/L) VERSUS DEPTH BELOW SURFACE (ft)



000327

FINAL

FIGURE G-15
GEOPROBE™ RESULTS FOR LOCATION 12234
TOTAL URANIUM CONCENTRATION (µg/L) VERSUS DEPTH BELOW SURFACE (ft)

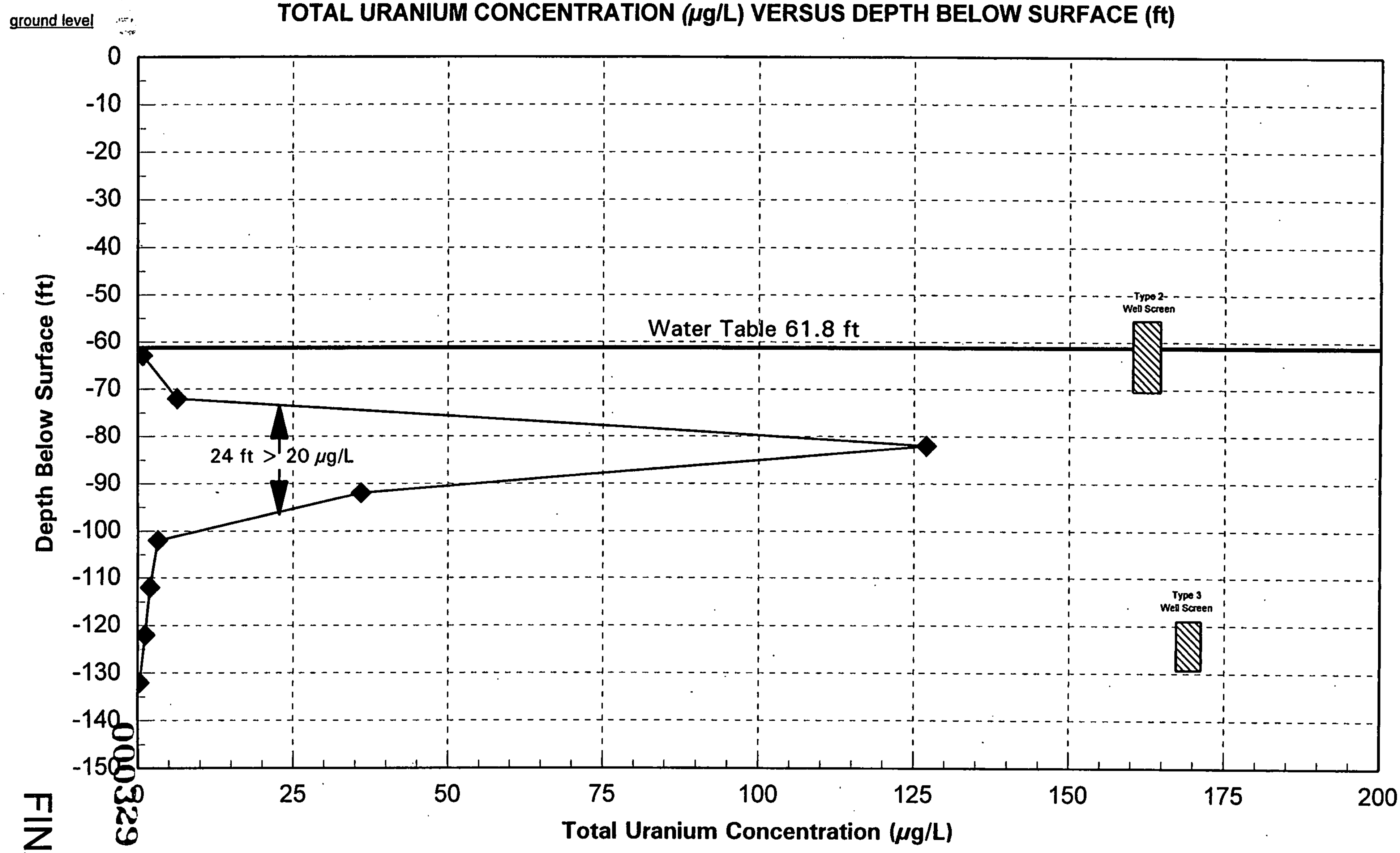


FINAL

000322

851

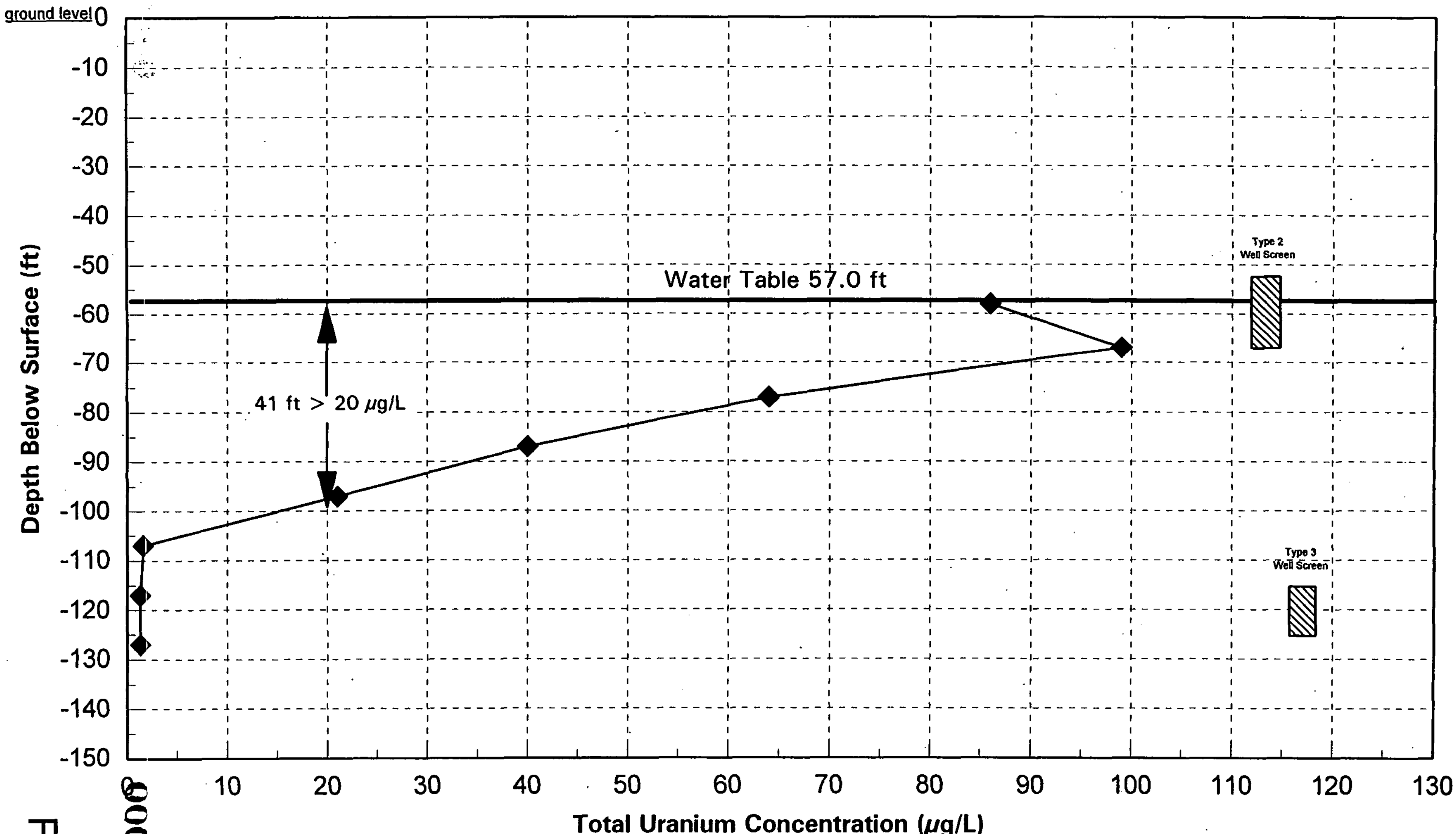
FIGURE G-16
GEOPROBE™ RESULTS FOR LOCATION 12235
TOTAL URANIUM CONCENTRATION (μg/L) VERSUS DEPTH BELOW SURFACE (ft)



FINAL

000329

FIGURE G-17
GEOPROBE™ RESULTS FOR LOCATION 12229
TOTAL URANIUM CONCENTRATION (µg/L) VERSUS DEPTH BELOW SURFACE (ft)

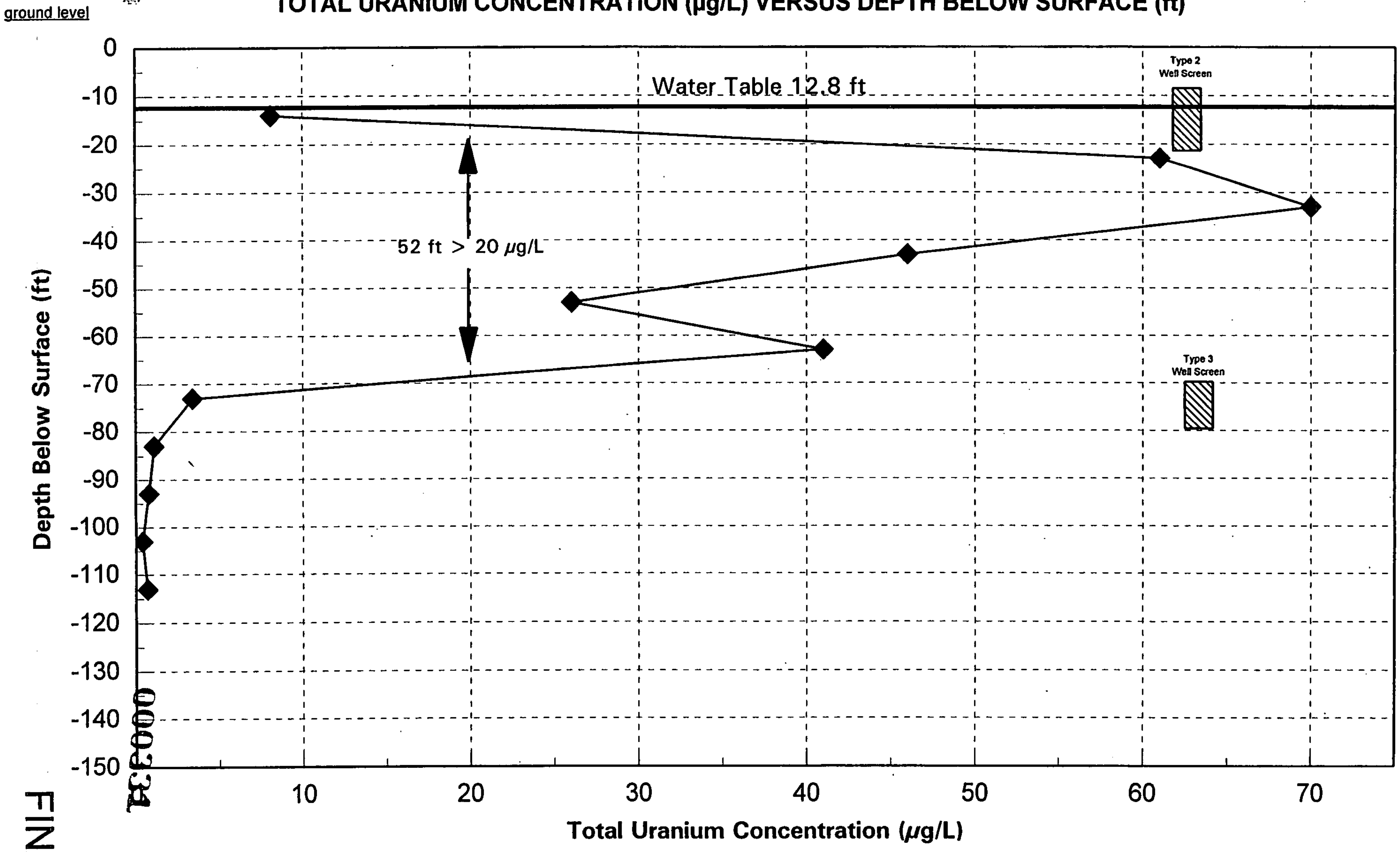


000330

FINAL

8651

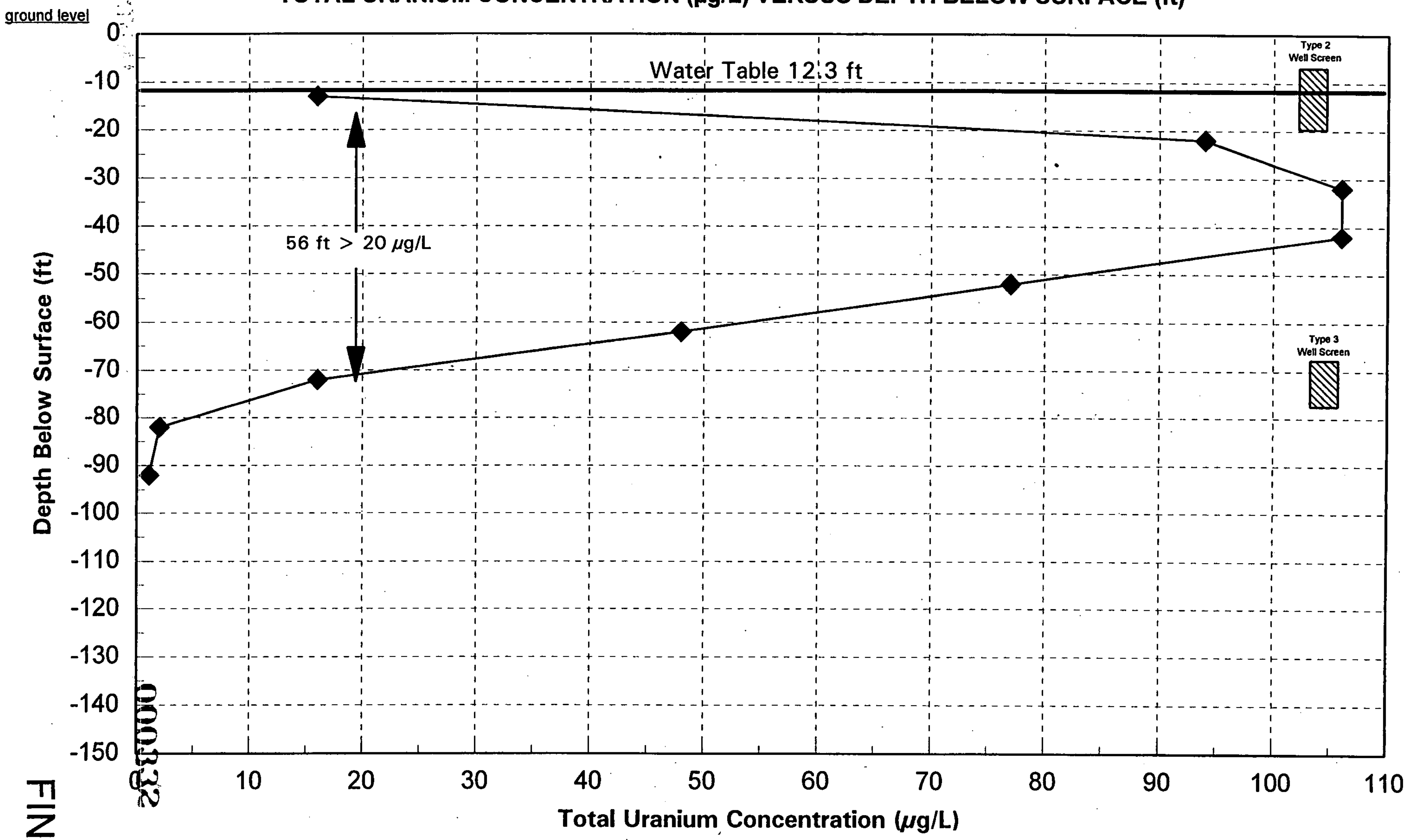
FIGURE G-18
GEOPROBE™ RESULTS FOR LOCATION 12236
TOTAL URANIUM CONCENTRATION (µg/L) VERSUS DEPTH BELOW SURFACE (ft)



000334

FINAL

FIGURE G-19
GEOPROBE™ RESULTS FOR LOCATION 12237
TOTAL URANIUM CONCENTRATION (µg/L) VERSUS DEPTH BELOW SURFACE (ft)

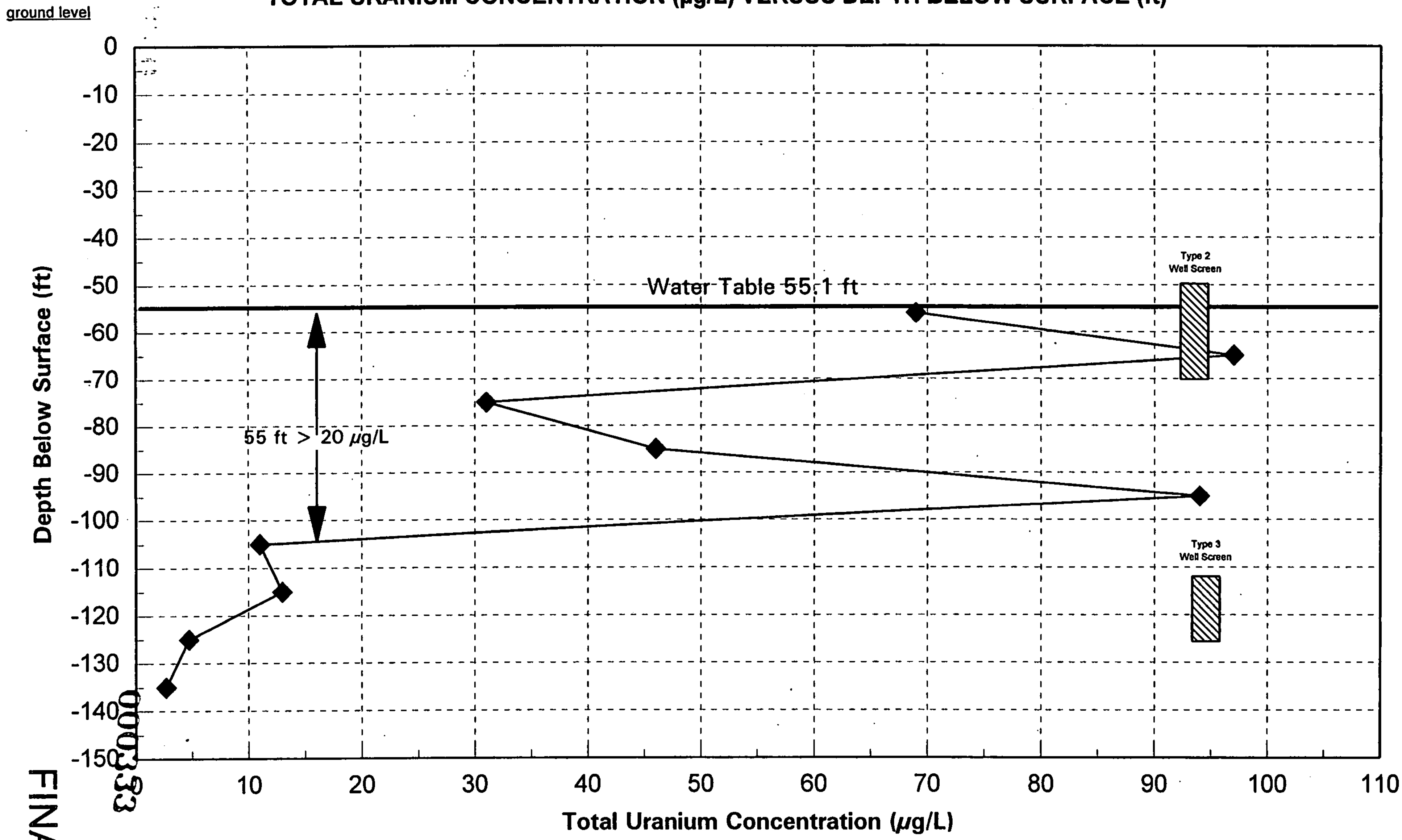


000332

FINAL

8651

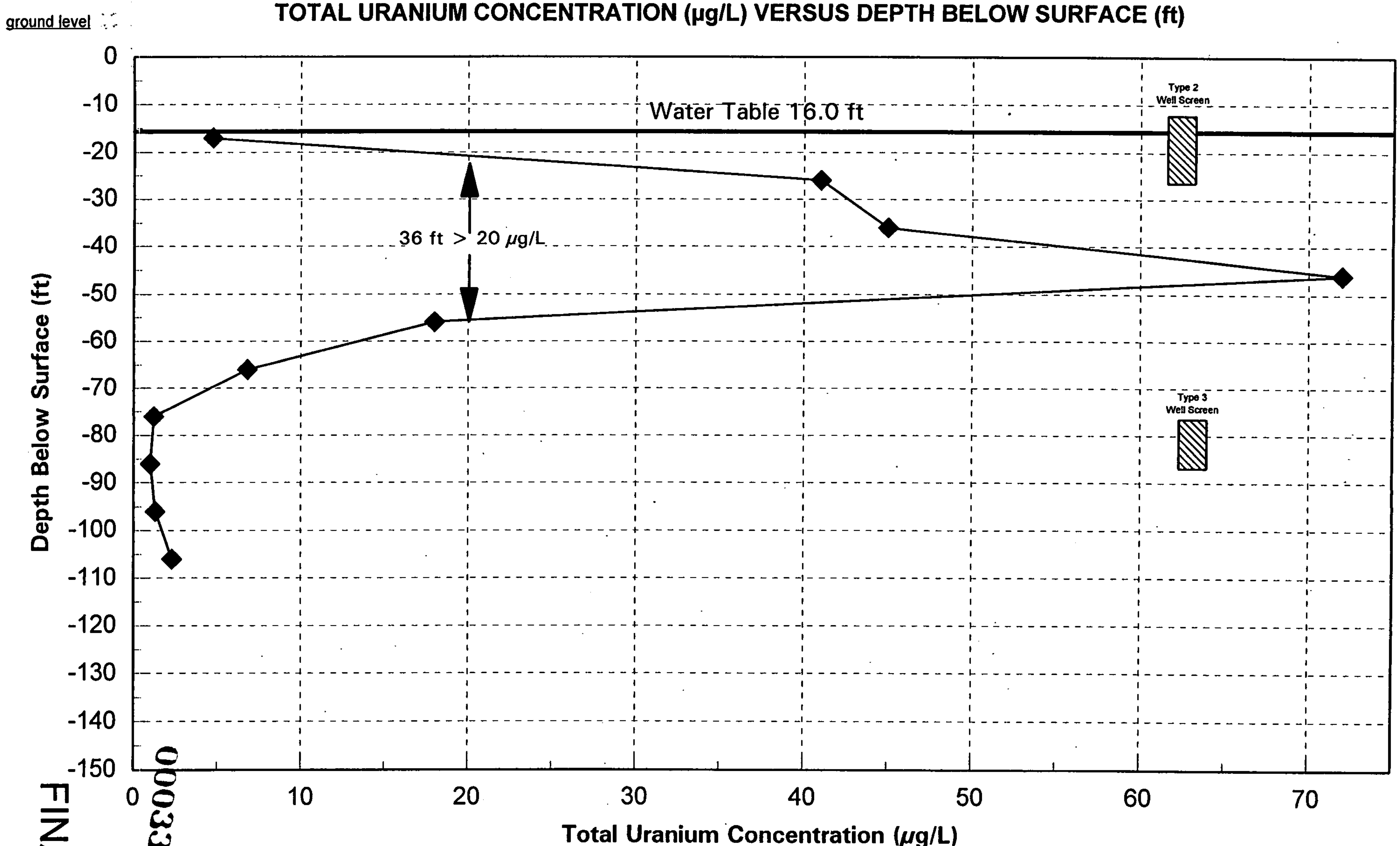
FIGURE G-20
GEOPROBE™ RESULTS FOR LOCATION 12238
TOTAL URANIUM CONCENTRATION (µg/L) VERSUS DEPTH BELOW SURFACE (ft)



000333

FINAL

FIGURE G-21
GEOPROBE™ RESULTS FOR LOCATION 12241
TOTAL URANIUM CONCENTRATION (µg/L) VERSUS DEPTH BELOW SURFACE (ft)

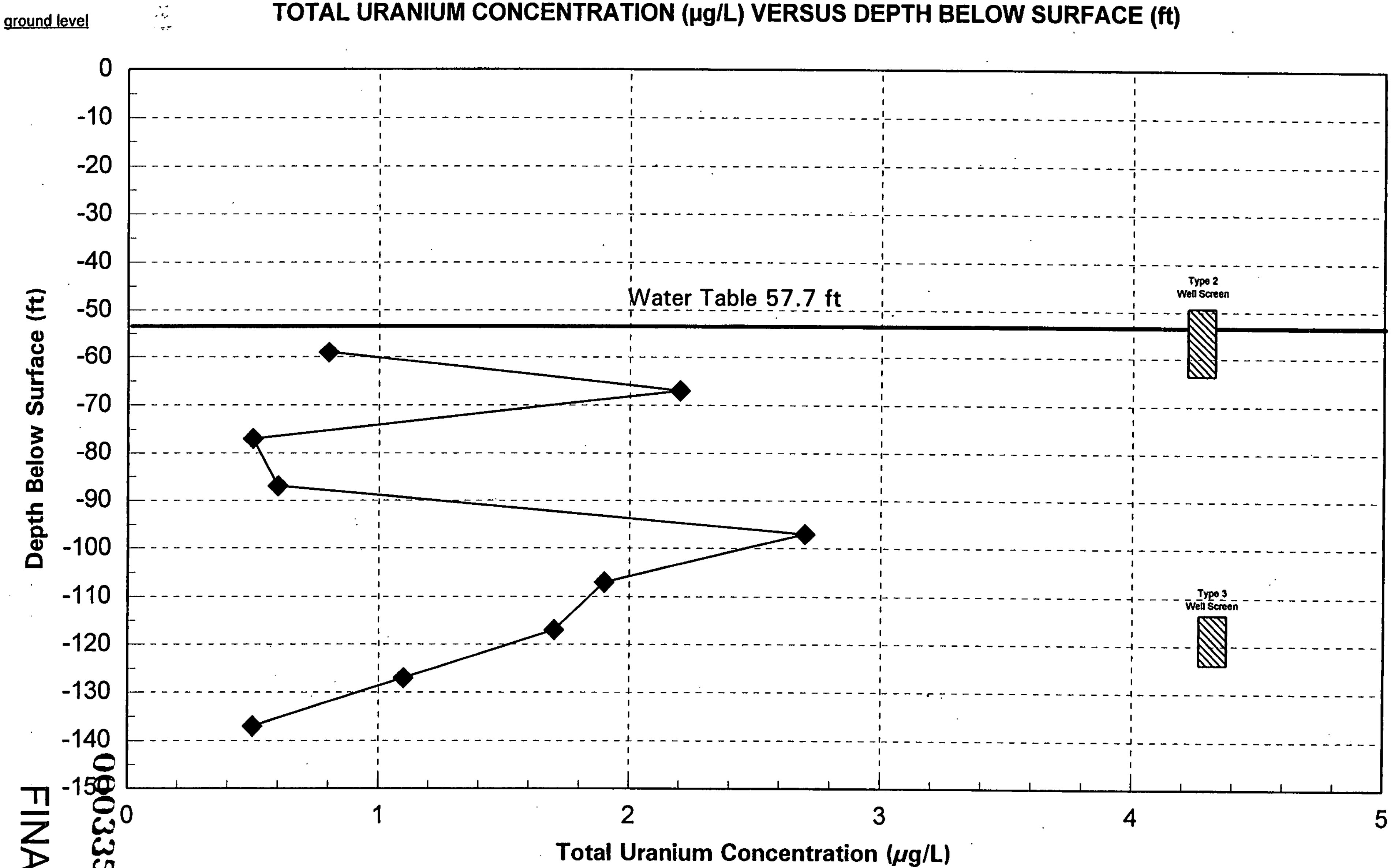


FINAL

000334

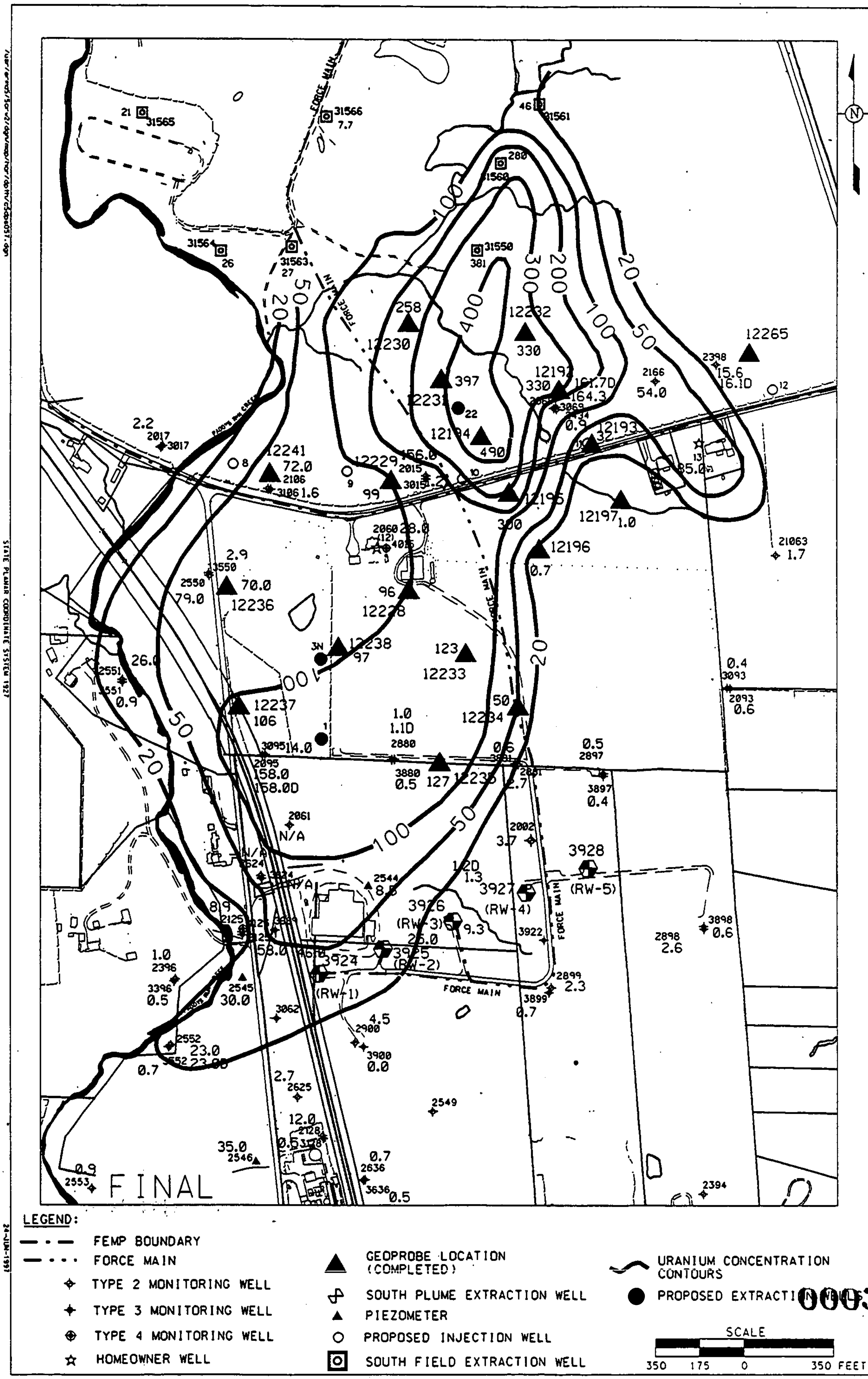
8651

FIGURE G-22
GEOPROBE™ RESULTS FOR LOCATION 12265
TOTAL URANIUM CONCENTRATION (µg/L) VERSUS DEPTH BELOW SURFACE (ft)



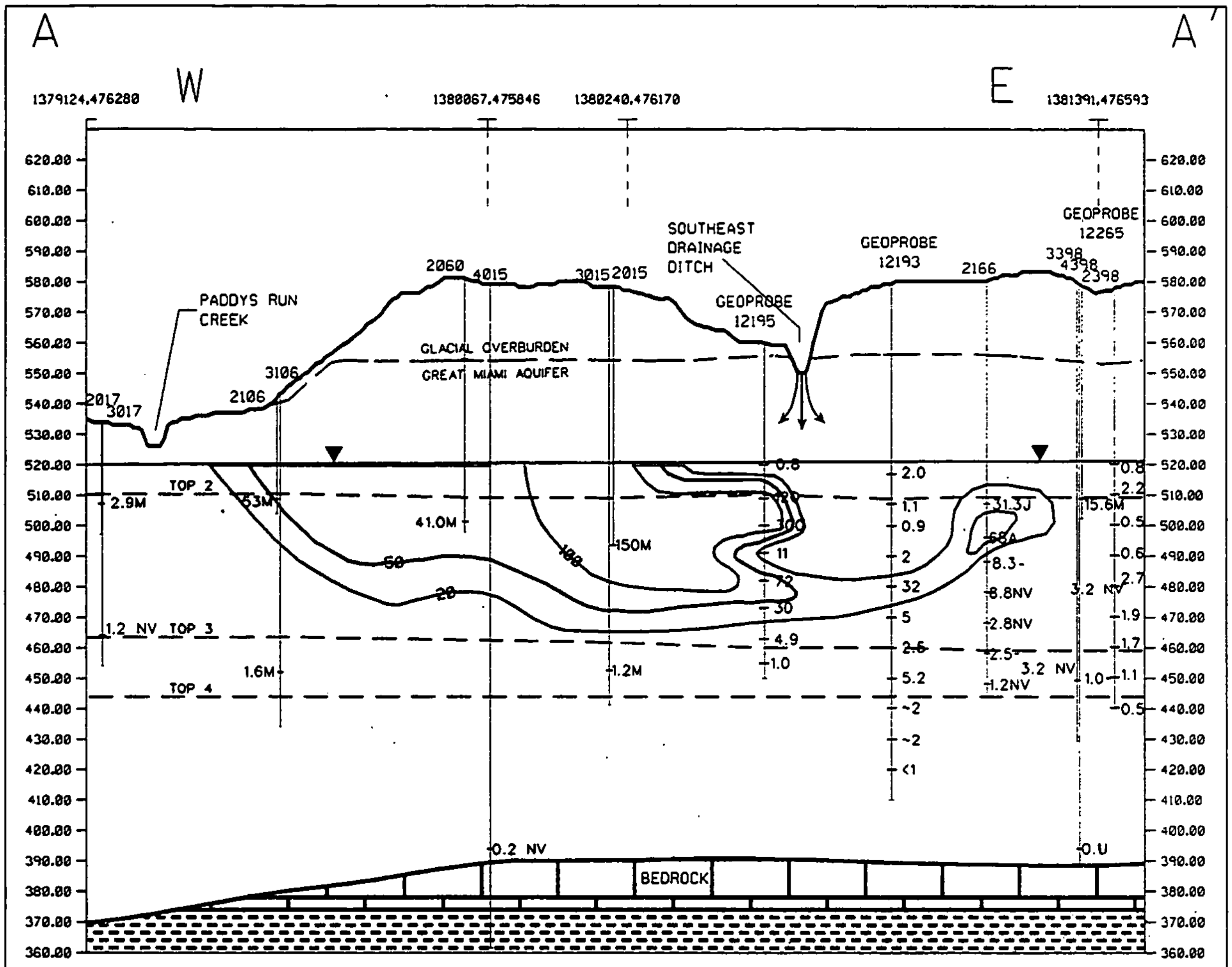
000335

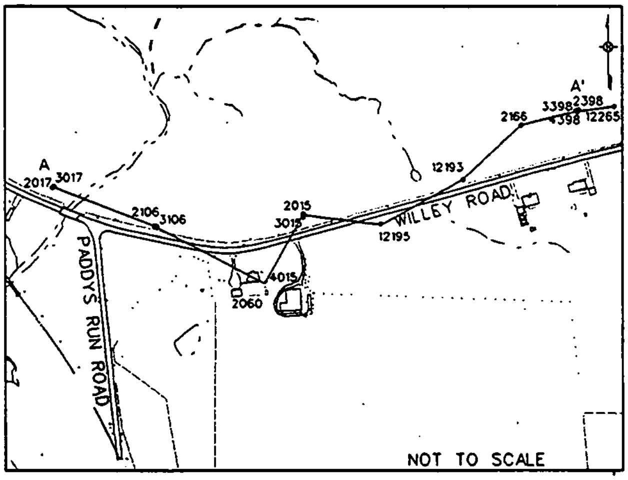
FINAL



000336

FIGURE G-23. MAXIMUM TOTAL URANIUM PLUME MAP





LEGEND:

+ 77.1 TOTAL URANIUM IN GROUNDWATER (ug/L)

REPRESENTS INFILTRATION OF "CLEAN" SURFACE WATER

DATA QUALIFIERS:

NV = NONVALIDATED
- = VALIDTED, NOT QUALIFIED
J = VALIDATED, ESTIMATED
M = MAXIMUM OF 1996 3rd., AND 4th. QUARTER DATA

NOTE:

NON-GEOPROBE VALUES ARE FROM 1993 SNAPSHOT DATA UNLESS QUALIFIED WITH AN "M".
THE WATER ELEVATION SHOWN IS ESTIMATED.

000337

SCALE
500 250 0 500 FEET

FINAL

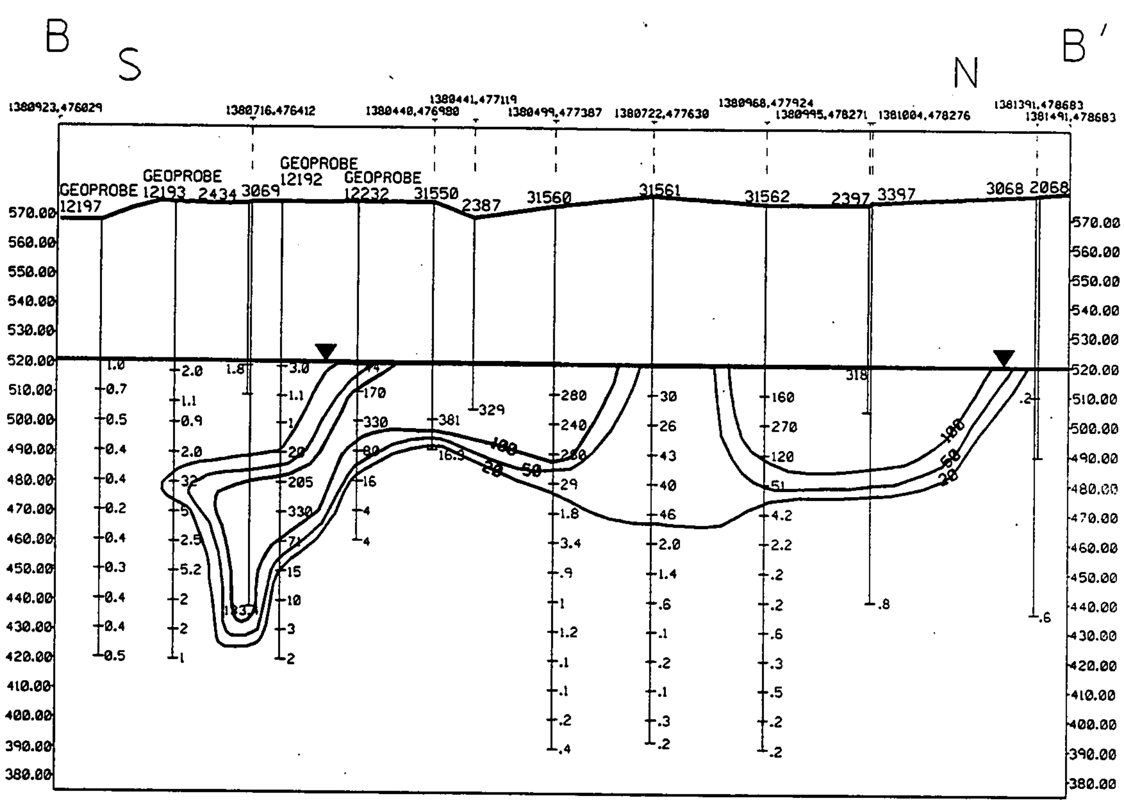
FIGURE G-24. TOTAL URANIUM IN GROUNDWATER CROSS-SECTION A-A'

/usr/erma5/5crw2/dgn/map/hor/dpth/pspsec04.dgn

STATE PLANAR COORDINATE SYSTEM 1927

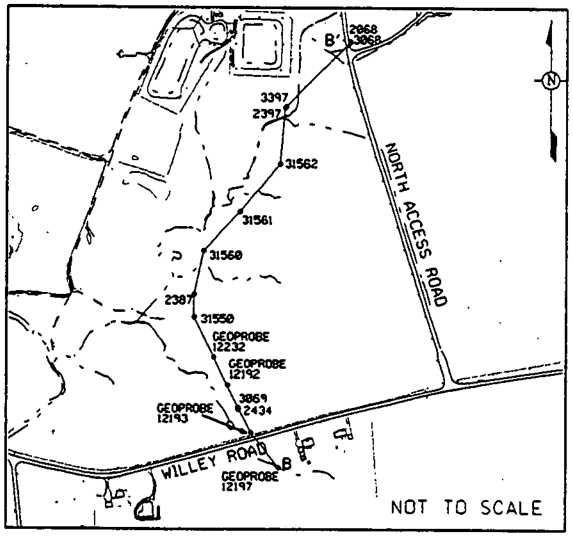
24-JUN-1997

/usr/ermo5/5crw2/dgn/map/hor/dpth/pspsec02.dgn



LEGEND:

TOTAL URANIUM IN GROUNDWATER (ug/L)



NOTE:

NON-GEOPROBE VALUES ARE FROM 1993 SNAPSHOT DATA. VALUES FOR EXTRACTION WELLS 31550, 31560, 31561 AND 31562 WERE COLLECTED WHEN THE WELLS WERE INSTALLED BY HYDROPUNCH

STATE PLANAR COORDINATE SYSTEM 1927

24-JUN-1997

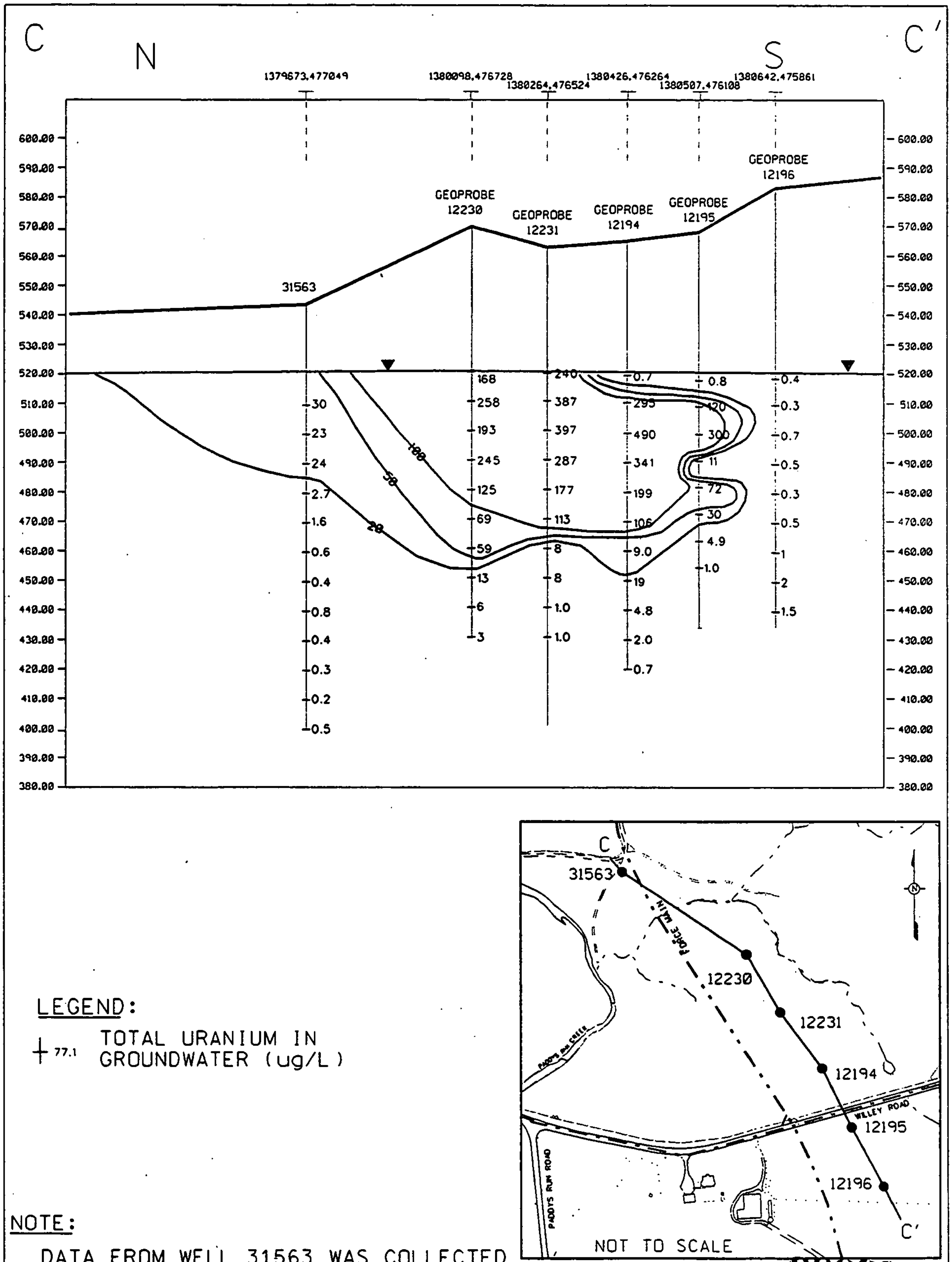
000338

SCALE

650 325 0 650 FEET

FINAL

FIGURE G-25. TOTAL URANIUM IN GROUNDWATER CROSS-SECTION B-B'



LEGEND:

+ 77.1 TOTAL URANIUM IN GROUNDWATER (ug/L)

NOTE:

. DATA FROM WELL 31563 WAS COLLECTED WHEN WELL WAS INSTALLED BY HYDROPUNCH.

000339

SCALE

500 250 0 500 FEET

STATE PLANAR COORDINATE SYSTEM 1927

24-JUN-1997

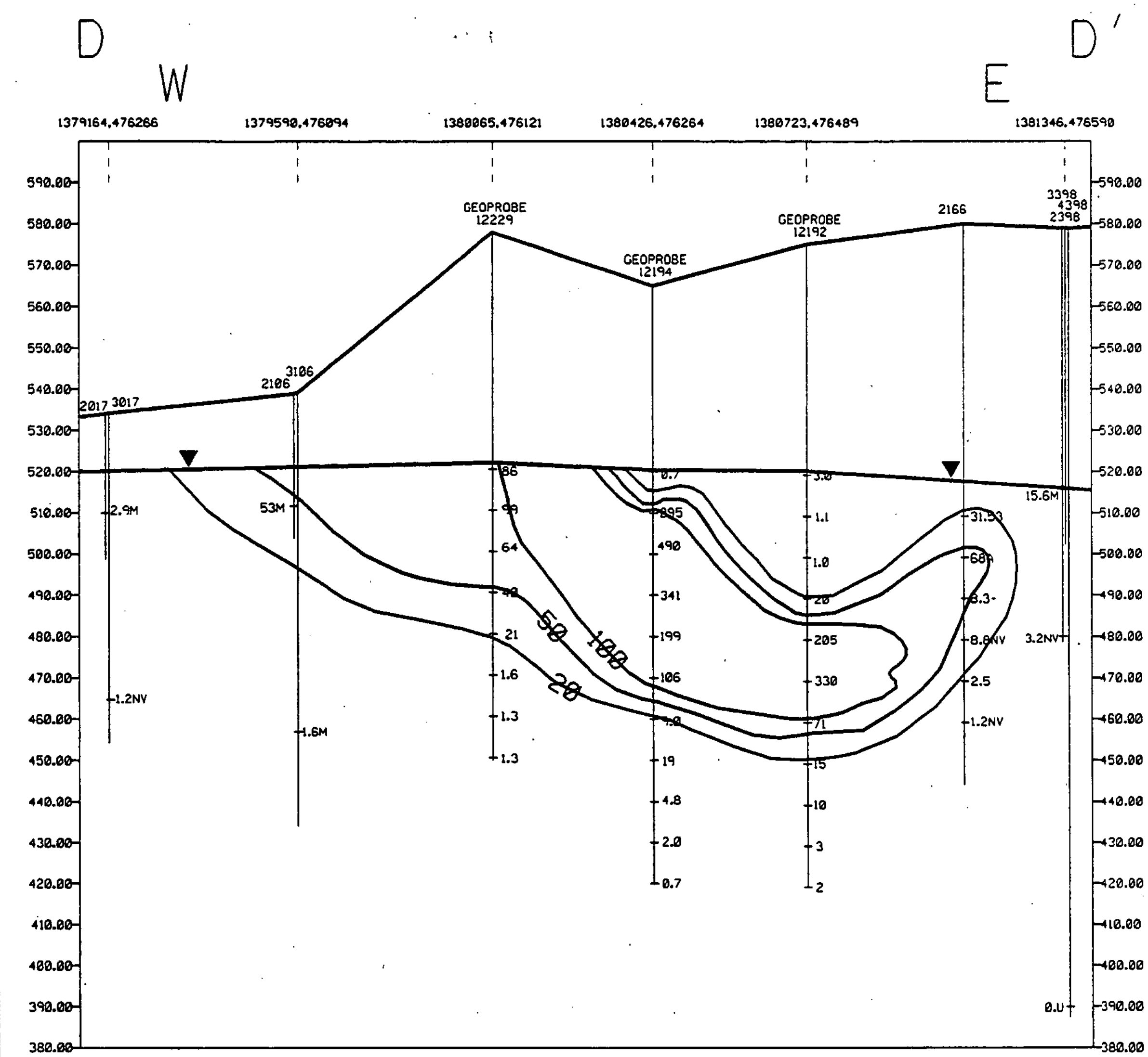
FINAL

FIGURE G-26. TOTAL URANIUM IN GROUNDWATER CROSS-SECTION C-C'

/usr/ermd5/5crw2/dgn/map/hor/dpth/pspsec08.dgn

STATE PLANAR COORDINATE SYSTEM 1927

24-JUN-1997

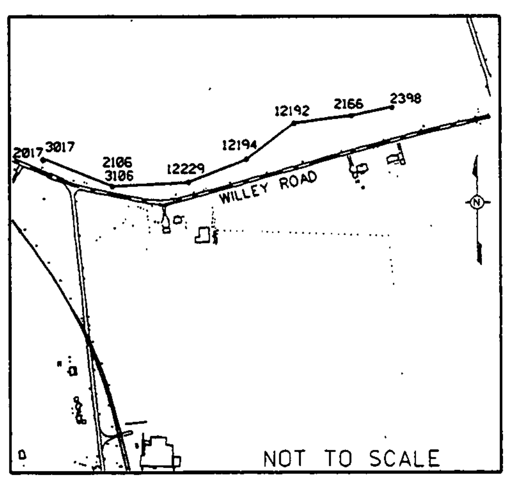


LEGEND:

TOTAL URANIUM IN GROUNDWATER (ppb)

DATA QUALIFIERS:
- U = UNDETECTED
- NV = NONVALIDATED
- \- = VALIDTED, NOT QUALIFIED
- J = VALIDATED, ESTIMATED
- M = MAXIMUM OF 1996 3rd. AND 4th. QUARTER DATA

NOTE:
NON-GEOPROBE VALUES ARE FROM 1993 SNAPSHOT DATA UNLESS QUALIFIED WITH AN "M". THE WATER ELEVATION SHOWN IS ESTIMATED.



000340

SCALE

450 225 0 450 FEET

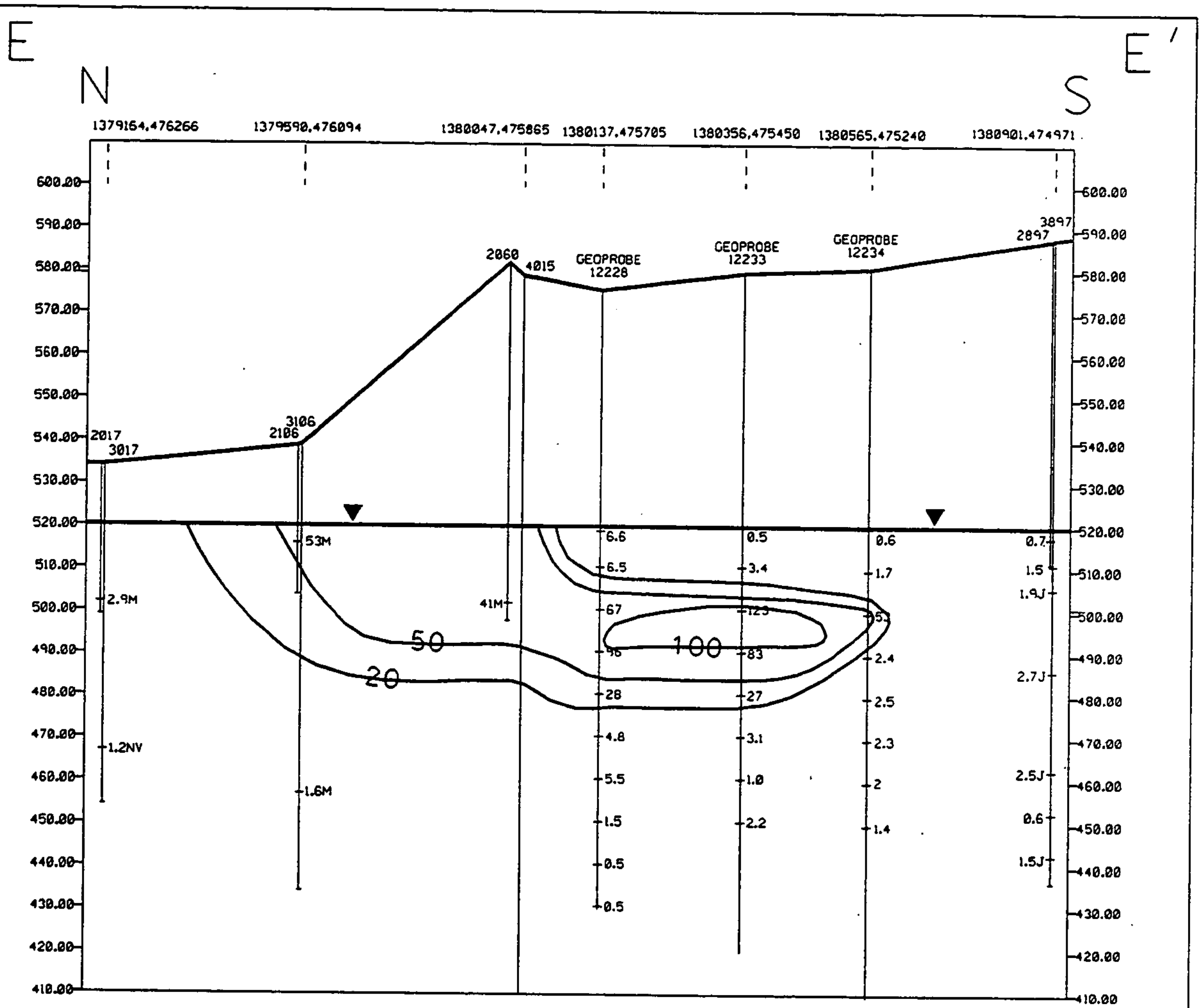
FINAL

FIGURE G-27. TOTAL URANIUM IN GROUNDWATER CROSS-SECTION D-D'

/usr/ermo5/5crw2/dgn/map/hor/dpth/pspsec09.dgn

STATE PLANAR COORDINATE SYSTEM 1927

24-JUN-1997



LEGEND:

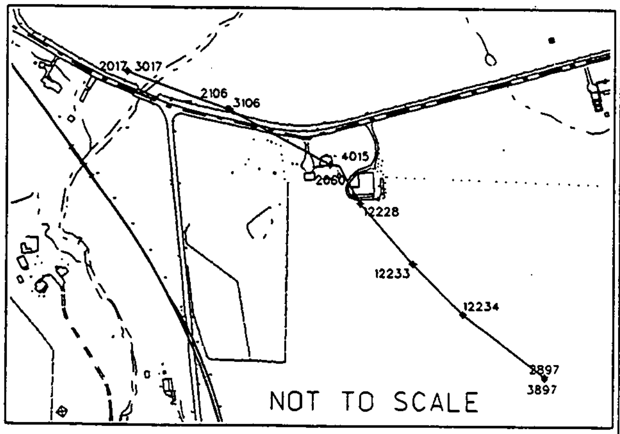
TOTAL URANIUM IN GROUNDWATER (ppb)

DATA QUALIFIERS:

U = UNDETECTED
NV = NONVALIDATED
– = VALIDTED, NOT QUALIFIED
J = VALIDATED, ESTIMATED
M = MAXIMUM OF 1996 3rd. AND 4th. QUARTER DATA

NOTE:

NON-GEOPROBE VALUES ARE FROM 1993 SNAPSHOT DATA UNLESS QUALIFIED WITH AN "M". THE WATER ELEVATION SHOWN IS ESTIMATED.



000341

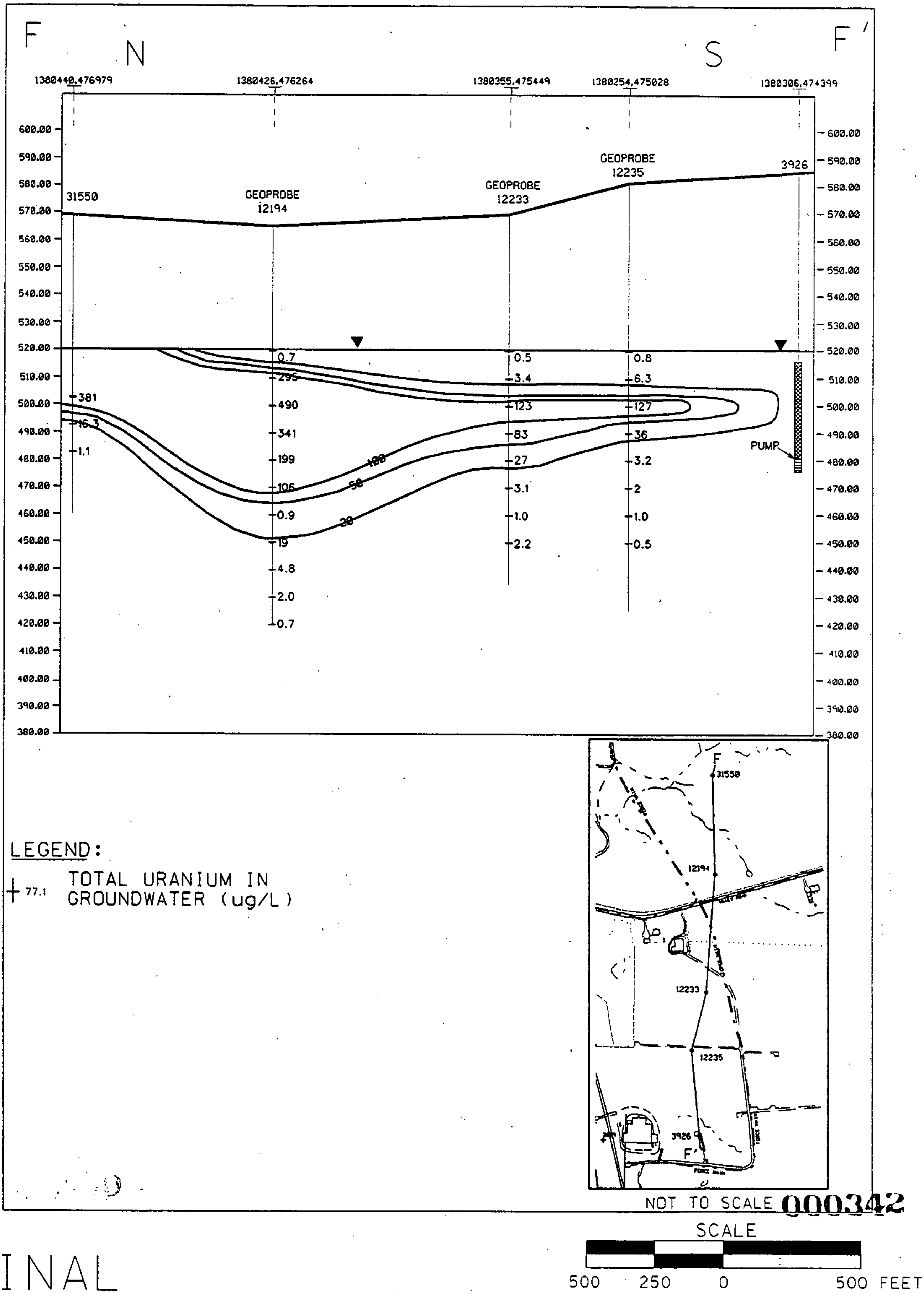
SCALE

450 225 0 450 FEET

FINAL

FIGURE G-28. TOTAL URANIUM IN GROUNDWATER CROSS-SECTION E-E'

/usr/ermo5/5crw2/dgn/map/har/dpth/pspsec07.dgn



STATE PLANAR COORDINATE SYSTEM 1927

24-JUN-1997

000342

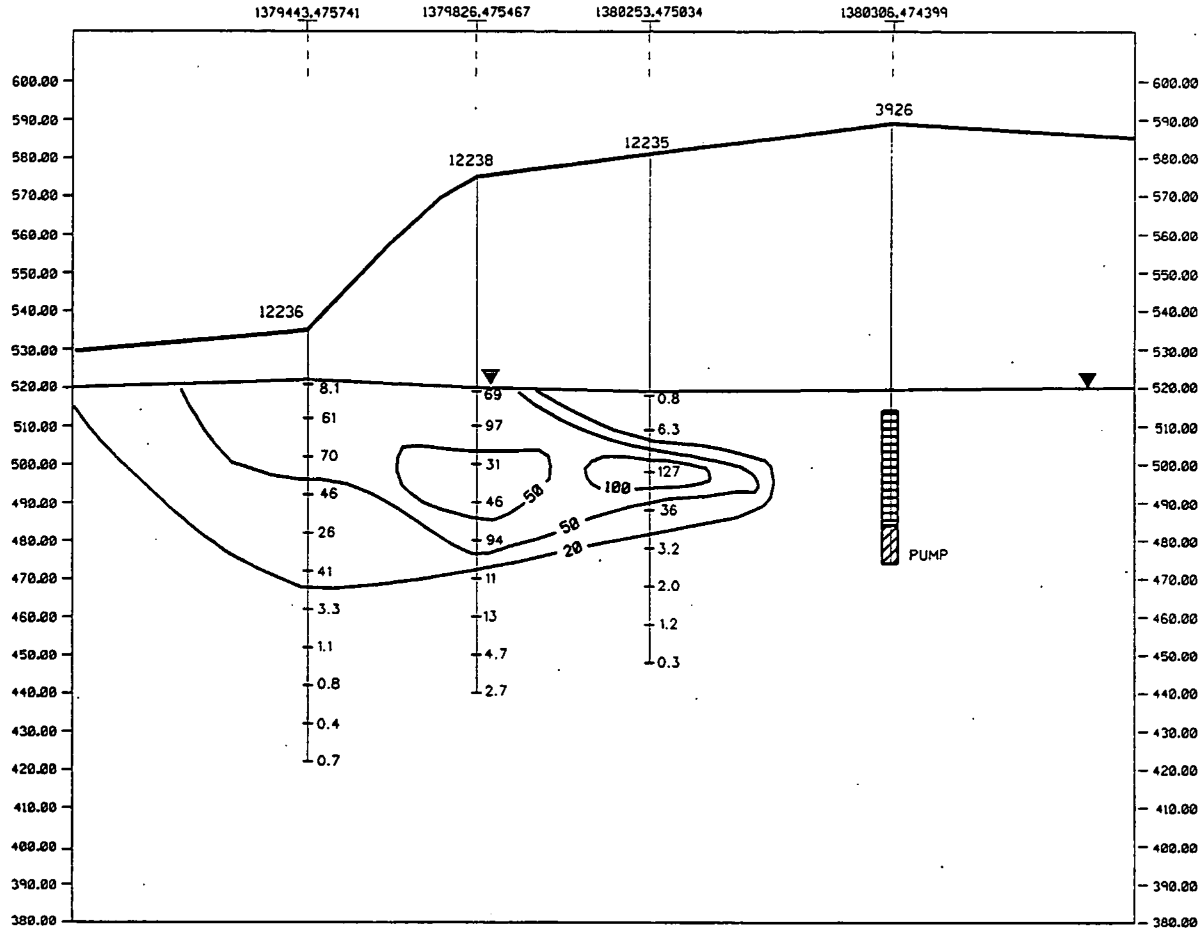
FINAL

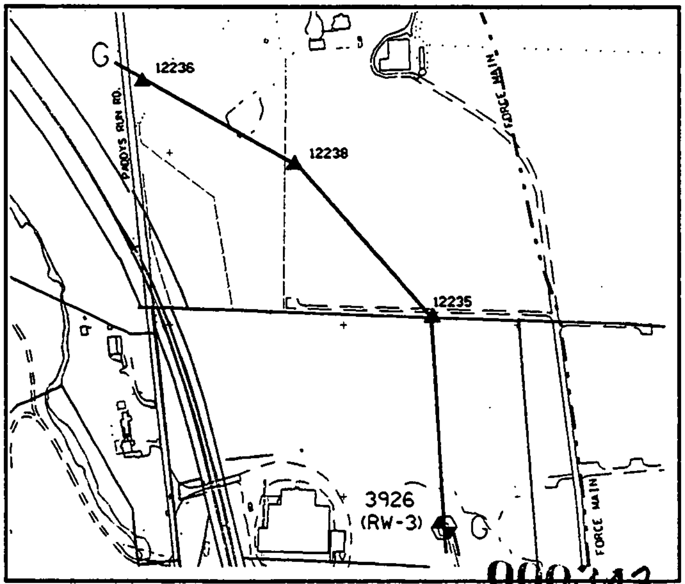
FIGURE G-29. TOTAL URANIUM IN GROUNDWATER CROSS-SECTION F-F'

/usr/ermd5/5crw2/dgn/map/hor/dpth/brsr069.dgn

STATE PLANAR COORDINATE SYSTEM 1927

24-JUN-1997





NOT TO SCALE

LEGEND:

+ 77.1 TOTAL URANIUM IN GROUNDWATER (ug/L)

000343

FINAL

SCALE

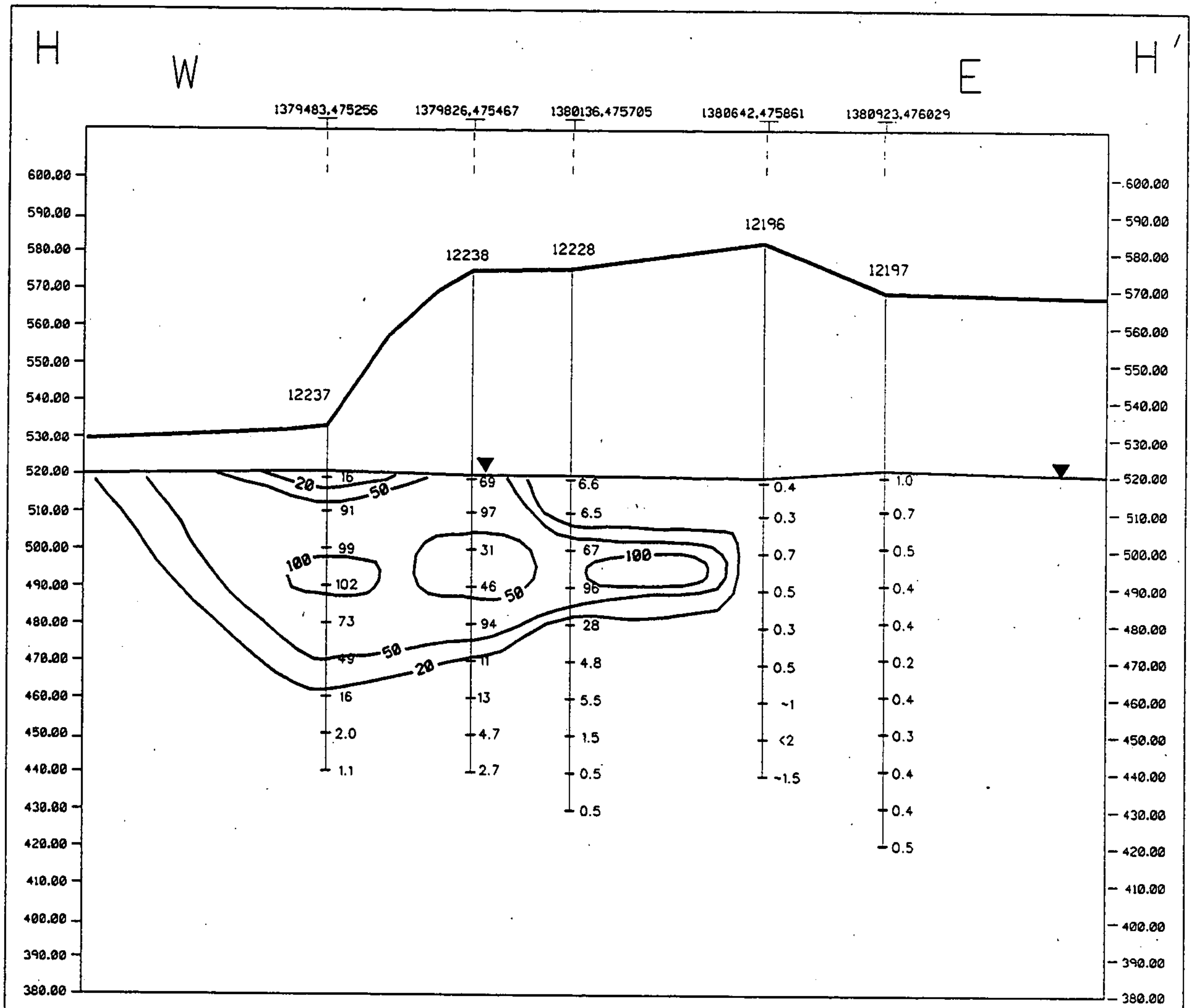
500 250 0 500 FEET

FIGURE G-30. TOTAL URANIUM IN GROUNDWATER CROSS-SECTION G-G'

/usr/erma5/5crw2/dgn/map/hor/dpth/brsr070.dgn

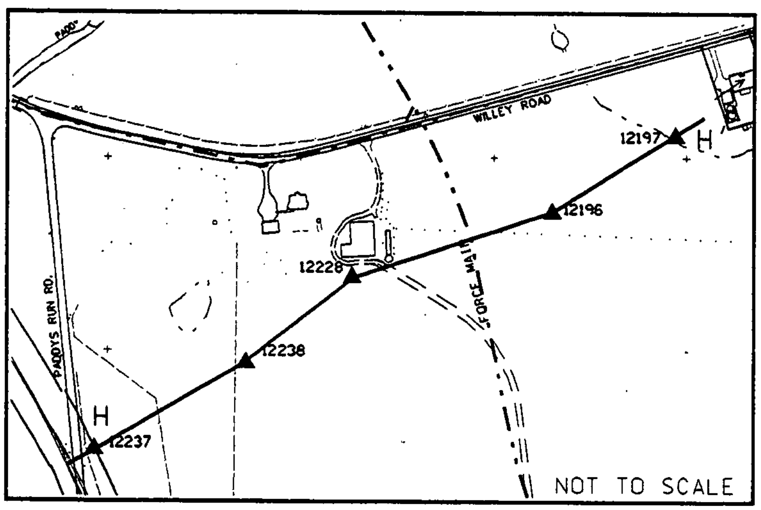
STATE PLANAR COORDINATE SYSTEM 1927

24-JUN-1997



LEGEND:

+ 77.1 TOTAL URANIUM IN GROUNDWATER (ug/L)



000344

SCALE

500 250 0 500 FEET

FINAL

FIGURE G-31. TOTAL URANIUM IN GROUNDWATER CROSS-SECTION H-H'

/usr/ermo5/5crw2/dgn/map/har/dpth/brsr077.dgn

STATE PLANAR COORDINATE SYSTEM 1927

24-JUN-1997

LEGEND:

— · — · — FEMP BOUNDARY

– – – – KRIGING BOUNDARY

000345

SCALE

650 325 0 650 FEET

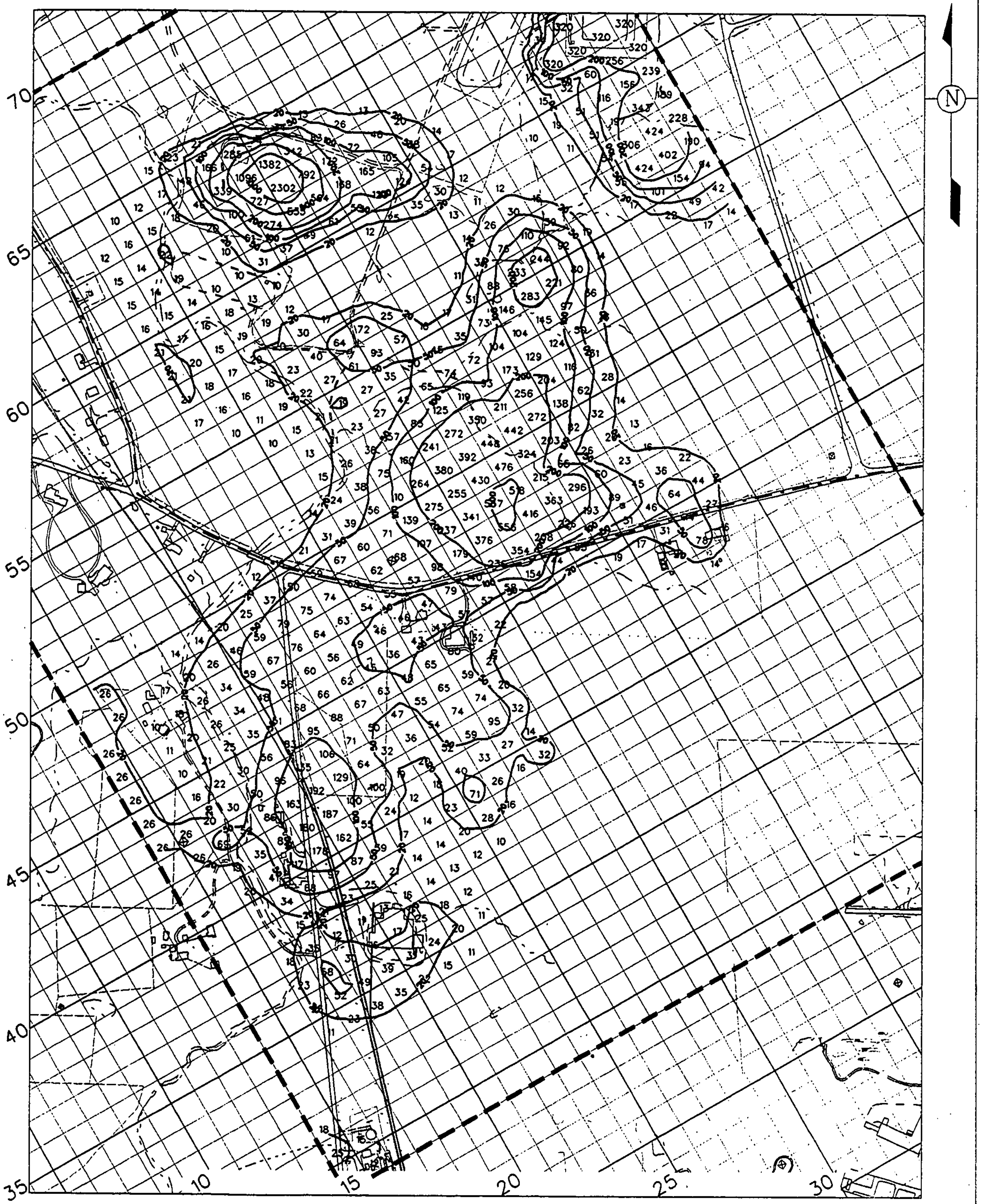
FINAL

FIGURE G-32. KRIGED MAXIMUM TOTAL URANIUM PLUME MAP, LAYER 1

/usr/ermd5/5crw2/dgn/map/hor/dpth/brs078.dgn

STATE PLANAR COORDINATE SYSTEM 1927

24-JUN-1997



LEGEND:

FEMP BOUNDARY

KRIGING BOUNDARY

000346

SCALE

650 325 0 650 FEET

FINAL

FIGURE G-33. KRIGED MAXIMUM TOTAL URANIUM PLUME MAP, LAYER 2

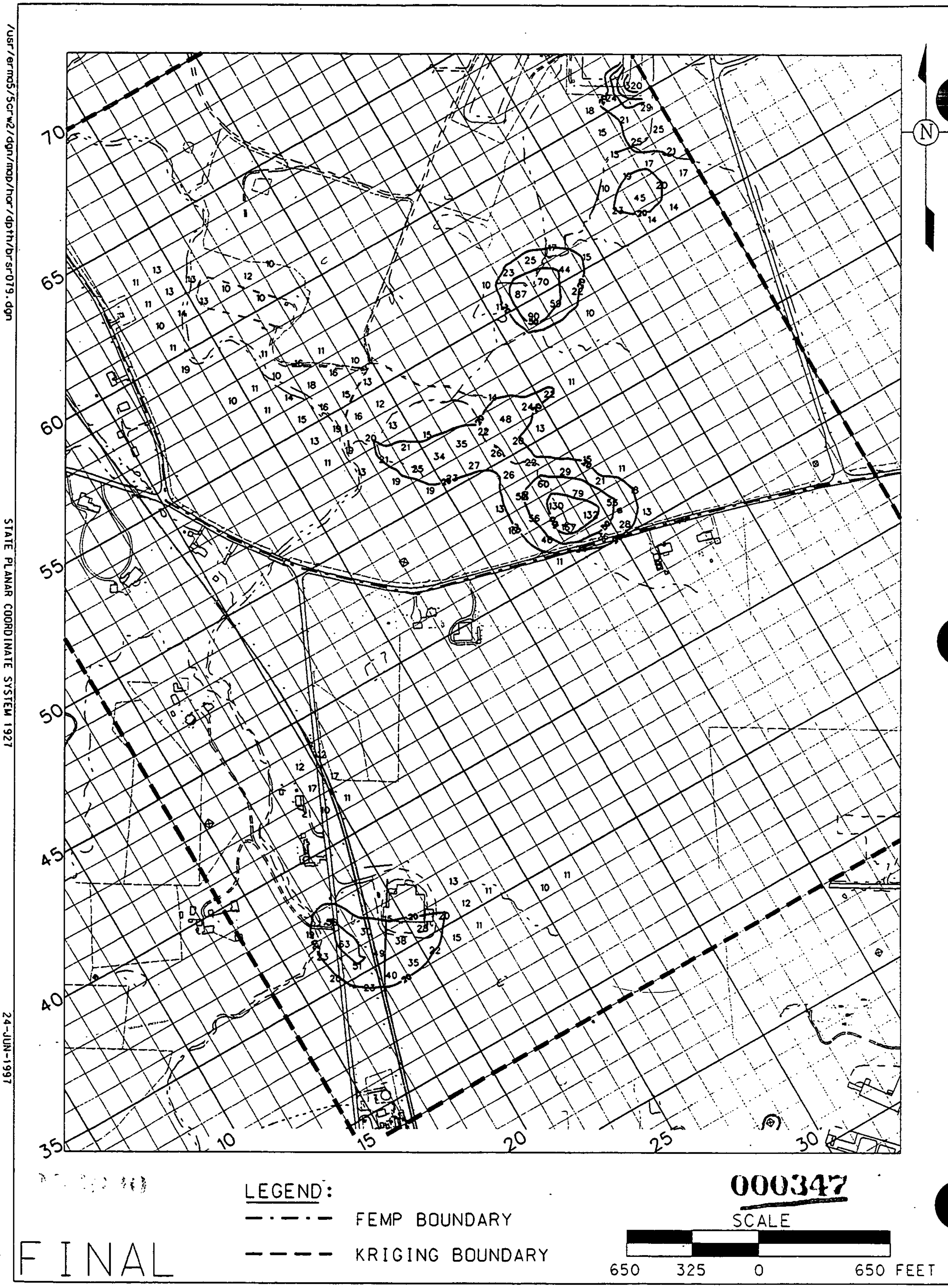


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FIGURE G-34. KRIGED MAXIMUM TOTAL URANIUM PLUME MAP, LAYER 3